" Form only exists trhough light and our perception about the world around us is totally dependent on this "

Claude Monet

NATURAL LIGHTING FOR SUSTAINABLE DESIGN OF ART EXIBITION SPACES

DAYLIGHTING DESIGN CATALOGUE

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ABSTRACT

The present thesis is a research work about natural lighting oriented to sustainable design of art exhibition spaces like galleries and museums, which aims to expose a strategy for the use of daylight and sustainability into architecture. Initially there was a description of some of the main methods and evolution surrounding natural lighting as a sustainable design approach. Chapter 2 explores natural lighting characteristics, chapters 3 and 4 present study cases analysis, chapters 5, 6, 7, 8 and 9 rides a text and images that involves aspects of design and daylight strategies developed through an experiment. All theories in this work is an epistemological level that opens new avenues for design exploration. This investigation exposes empirical strategies of using a daylight catalogue to the development of sustainable solutions concerning light control. For this, it is used historical background to study how natural light was used in the contemporaneity in order to apply new concepts of sustainability. The light has the power to change the space sensation and to give us time perception. Its an element available in nature that can save energy, promote health and enhance art experience.

***Keywords**: Natural lighting, sustainability , exhibition spaces, daylight design, light system control*

ABSTRACT

Esta tese é um trabalho de pesquisa sobre luz natural orientada ao design sustentável de espaços de exibição de arte como galerias e museus, que objetiva expor estratégias para o uso da luz natural de forma sustentável na arquitetura. Inicialmente foi descrito alguns métodos e evolução sobre a luz do dia . O capítulo 2 explora a luz solar em suas características, capítulos 3 e 4 apresentam casos de estudo, capítulos 5, 6, 7, 8 e 9 explicitam textos e imagens que invocam aspectos de estratégia de design e luz natural desenvolvidos através de um experimento. Todas as teorias deste trabalho são níveis epistemológicos que abrem novos caminhos para a exploração do design. Esta investigação expõe estratégicas empíricas usando um catálogo de luz do dia para orientar soluções sustentáveis relacionadas ao controle da luz. Para tanto, foi estudado história do uso da luz solar na contemporaneidade a fim de aplicar novos conceitos. A luz tem o poder de mudar a sensação do espaço e a percepção do tempo. É um elemento disponível na natureza que pode economizar energia, recursos, promover a saúde, o bem estar e incrementar a experiência da arte.

***Palavras-chave**: Luz natural, sustentabilidade , espaços de arte, design de iluminação, controle da luz*

ACKNOWLEDGMENTS

To God, that created natural light sources,

To my beloved mother Eunice Guimaraes and my aunt Vera Macedo whom have gave me support and love.

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1.Introduction

INTRODUCTION

Natural lighting is one of the main human life source. Since the beginning of human evolution, the sun was venerated as a God and its light has a profound significance into people culturally, religiously, psychologically and emotionally. Cultures lead to light differently and architecture has the function of protect, diffuse, dominate, filter the natural light. Talking about architecture is talk about space. Space that is limited by the interaction between light and shadow. Brightness that enlighten and reveal the beauty of the spaces and nature Light that evokes time through the changes in color temperature and intensity during the day. Time is light that goes by. The shadow of the night that brings reclusion and darkness and veil the form of the things in a game that play naturally ride and seek with the human perception.

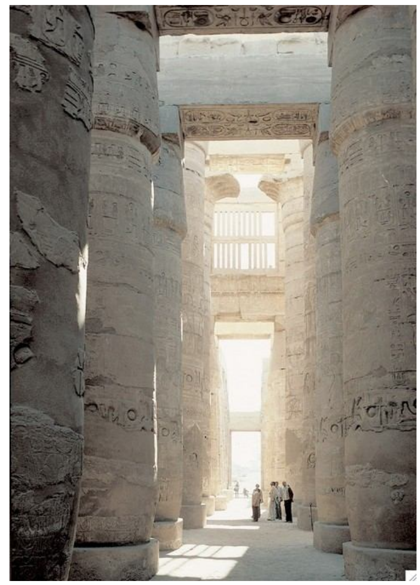

Fig-1: Indication of different strategies used at the Great Temple of Ammon, Karnak. i.e. clerestories and roof slits. Note the thick walls in the plan and presence of several columns that enable diffusion of daylighting. Available at http://www.greatbuildings.com

"En la historia de las sociedades, la medida del tiempo ha tenido un papel primordial. El dia y su luz son la referencia, el canon principal de esta medida donde la noche es la interrupción estructurante que de alguna manera delimita las diferencias de temporalidad. De igual manera asociamos las luces azuladas a la mañana y las doradas al atardecer, y distinguimos la primavera del invierno por los cambios de luz. Ese conocimiento instintivo de como es la luz que va a venir a continuación nos produce una sensación de estabilidad dentro del movimiento del mundo" [1].

Sustainability is the process of change, in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations. The organizing principle for sustainability is sustainable development, which includes the following interconnected domains: environment, economic and social. Sub-domains of sustainable development have been considered also: cultural, technological and political. Sustainable development, is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Brundtland Report for the World Commission on Environment and Development (1992) introduced the term of sustainable development.

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1 Elisa Ramos, *La Materia Intangible - Reflexiones Sobre La Luz En El Proyecto de Arquitectur*a.(Spain:Memorias Culturales, 2004), 13

Sustainability can also be defined as a socio-ecological process characterized by the pursuit of a common ideal. An ideal is by definition unattainable in a given time and space. However, by persistently and dynamically approaching it, the process results in a sustainable system.

Time and space is the line of this study delineated by natural light and it's inherent emotional and aesthetic aspects applied to sustainability. The relevance of the use, planning and control of natural light into art exhibition spaces is a wise design decision once it reduces the use of electricity, it doesn´t damage artwork, allows interaction between interior & exterior, promote well-been.

1.1 AIMS AND OBJECTIVES

The aim of this research is analyze how natural lighting can be used and designed to sustainable solutions based on a catalogue that guides design strategies concerning daylight control and characteristics applied to art exhibition spaces.

1- Research natural lighting and control elements for sustainable design

2- Study interactive architecture daylight layout

3 – Research history of the evolution of natural lighting design in the contemporaneity

4- Design a daylighting catalogue based on a natutal light experiment from a model unity box

5- Design an implementation project for the original upper galleries of the Can Framis Museum in Barcelona.

1.2 STRUCTURE OF THE STUDY

This study is divided into eight chapters including the introduction and the conclusion. The introduction outlines the general presentation, the aims and objectives of the research and summarizes the structure of the study. Chapter two provides a review of the literature relating to the theme and insert a reflection on the use of natural lighting and its characteristics. Chapter three presents the study cases. Chapter four points out the methodology of data collection in the Cam Framis Museum and analysis . Chapter five mentions the experiment process and its registers. Chapter six presents the daylight catalogue conception and applications. Chapter seven provides the implementation project for Cam Framis Museum as a result of the use of the catalogue. Chapter eight is the final conclusion.

1.3 HYPOTHESIS

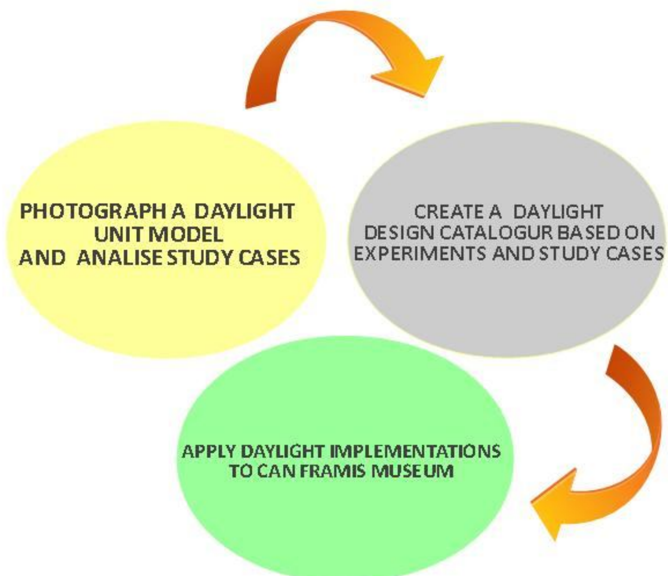
Although computer programs are a powerful instrument to calculate project lighting and can be easier to manipulate data, it does not give us a realistic view and interpretation of natural light. This thesis proposes the real use of daylight captured by photo register to analyze light quality among other aspects to help design decisions.

From this theory, the hypothesis is :

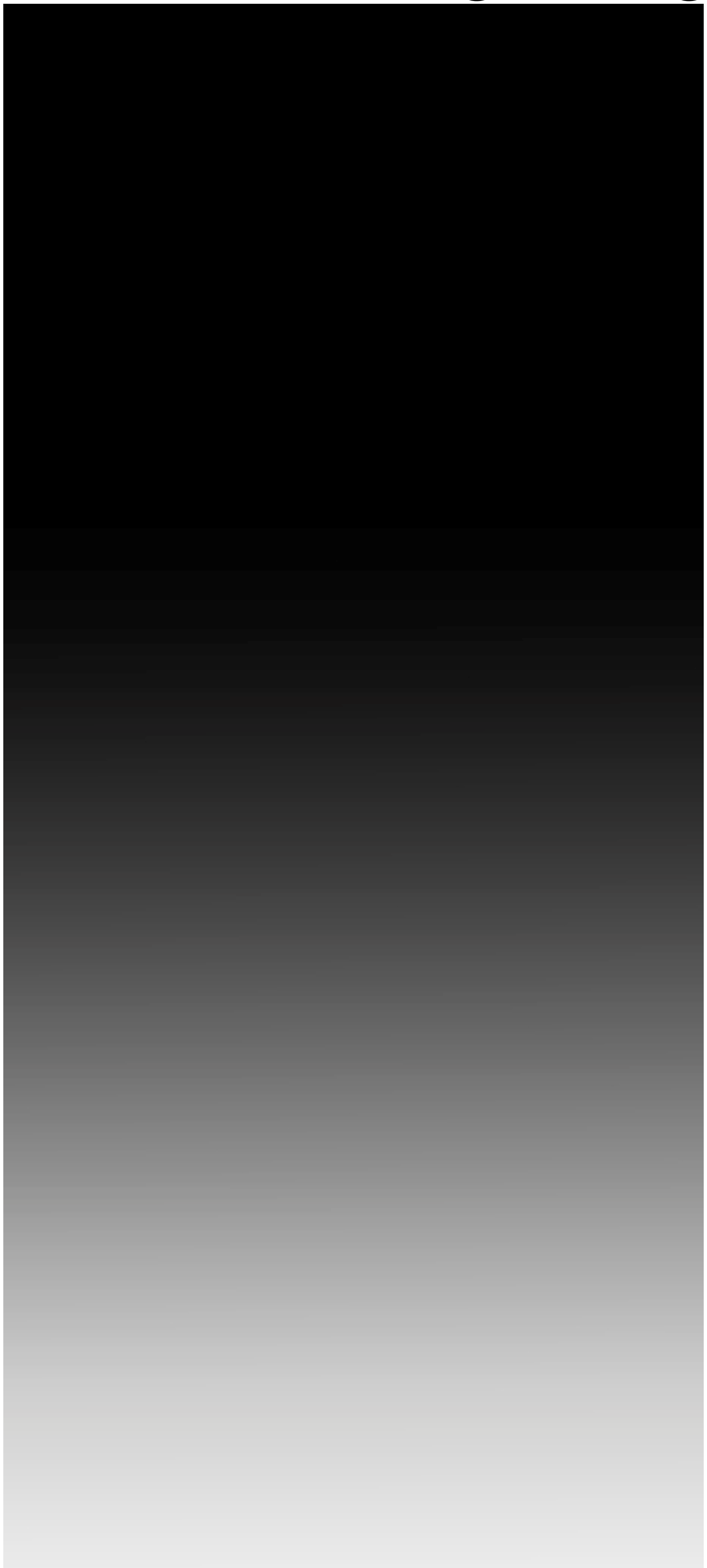
Real registers from daylight are more reliable and appropriate to guide lighting design decisions than digital simulations

1.4 METHODOLOGY

A unity model box will be created as a natural light experiment. This box will allow several tests modifying different materials and shapes to change/control light characteristics. The results will be used to develop a light design catalogue that can help designers to make project decisions concerning daylight at a sustainable approach. Finally this strategies will be used to propose an intervention at the upper galleries of the Cam Framis Museum in Barcelona, Spain.



2.Natural lighting



2.1 EVOLUTION OF NATURAL LIGHTING IN COMTEMPORANEITY

"Desde los anillos Neolíticos de piedra de stonehenge a los grandes conjuntos de Teotihuacan, desde el templo de Amon en Karnak la arquitectura se orienta frente al sol. La palabra '' orientación'' deriva de oriente. En las iglesias y templos cristianos se colocaba el altar siempre al este. el este, origen de la luz, es también fuente de vida. El oeste, en las culturas primitivas es los terrores de la muerte"[2]

"About 30 years ago there was a huge movement for the black box concept in galleries and museums and cutting everything off from the outside world, but we are now both metaphorically and literally opening the curtains"

Mark Sutton Vane, principal of Sutton Vane Associates Lighting Design

For centuries, daylight was the only light available as a primary source of daylighting in constructed spaces. The architecture of the day was dominated by the aspiration to span wide spaces and creating openings large enough to distribute daylight to building interiors. Before daylight was supplemented by artificial lighting in the late 19th Century, consideration of good daylight strategies was essential. Indeed, Le Corbusier in 1989, clearly identified the importance of light in architecture when he expressed the point that, "Architecture is the masterly, correct and magnificent play of volumes brought together in light ..." emphasizing that "...the history of architecture is the history of the struggle for light." In the mid-20th-century, electric light supplanted daylight in buildings, fortunately, during the last quarter of the 20th-century and early years of this century, architects and designers have recognized the importance and value of introducing natural light into buildings[3]

Light study is a human concern at all times. By the time of Euclides (cent. III bc) it was known the linear propagation of the light, the low of reflection and refraction. They think that light flew from the eyes to embrace objects in a wrong theory. The Platon vision suggested the opposite, the light rays come from the objects and bring information about light quality, surface and characteristics, perspective that remains till today.

2.1.2 THE MODERN MOVEMENT (1900S)

The pioneers of the modern movement, reacting to the ornamental excesses of the late Renaissance, used the freedom allowed by the technical developments of the industrial revolution to explore new building forms.

2 Ramos, La Materia Intangible, 23.

3 Nyole Chepchumba, "History of Daylighting Strategies: a comparative analysis across the periods." (Master diss., University of Nairobi, 2014), 3

Notable architects retained many principles of the historical site orientation, natural ventilation and daylight illumination while selectively incorporating the new technology. Economy-of-structure, space, ornament, labor and construction cost did not extend to energy, however. The electric lamp, structural frame, light-weight envelope materials notably the use of aluminum, large glass areas, waterproofing materials, the elevator, electronic sound amplification and communication systems—all increased energy usage. This was the price of these devices the freed architecture from the constraints of climate and site.

Fig-2: Le Corbusier’s Chapel at RonChamp. Windows at south facade

The new direction of architecture developed so rapidly and was so complex that it became impossible for a single individual to be knowledgeable in mechanical, electrical and structural systems. Specialists then emerged in each technical area, and the architect became dependent on them during the critical conceptual design phase regarding environmental control therefore losing the capacity to evaluate independently various technical choices in their effect on the overall design. In fact its characterization of the roof and south wall as a primary elements in the play of light and structure provides an opportunity to recast the architect's role. Via a provocative discussion that moves between means and ends, between references to ' the the shell of a crab' that became the roof of the chapel, walls which are absurdly but practically thick, a horizontal crack of light 10 cm wide that will amaze.[4]

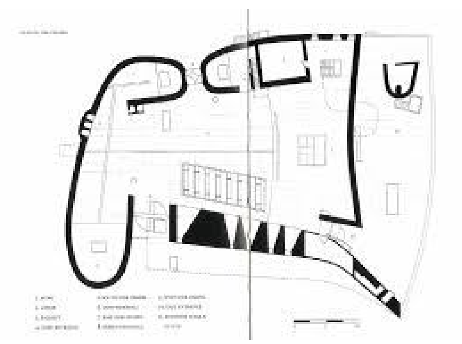


Fig-3: Le Corbusier’s Chapel at RonChamp. Floor plan

The interior of the RonChamp chapel is very dark. Although it has many windows, most of them let in little light because they are either very deep or very small. It is not easy to see at first. The spacial order and material character of the interior only emerge from the shadows, after the eyes have had time to adjust [5]. Le Corbusier evolved in this project his windows to a three dimensional depth, as its possible to see at north and south walls.The light symbolism is seen in three aspects, first is the sketch of the main processional door. The second point is the enigmatic image of a black sun on a ground of light against which the word RONCHAMP. The third is the Mary's niche, or more precisely its once a year split projection in sunlight at the dark floor.

“Architecture is the masterly, correct and magnificent play of masses brought together in light,”

Le Corbusier

4 Mary Ann Steane*, The Architecture of Light, Recent Approaches to Designing with Natural Lig*ht (Usa: routledge, 2011) 21.

5 Steane*, The Architecture of Light, 25.*

2.1.3 CATALAN MODERNISM

Modernism was especially privileged in Barcelona due to a set of particular conditions that allowed for the introduction of ‘the new’. Firstly, Spanish politics of the late 19th century was marked by increasing stability, with the reestablishment of the monarchy paving the way for rapid industrial expansion, particularly in Barcelona in the shipping, textile and manufacturing industries. This, of course, allowed for the growth of a wealthy middle class who would become patrons of the new style. Secondly, Barcelona played host to two world exhibitions in which Barcelona wanted to impress the international crowds, celebrate its economic growth and showcase its modernity: the 1888 Universal Exposition of Fine and Industrial Arts and the 1926 International Exhibition. Finally, the impetus for the development of Modernist architecture came from the availability of space in Barcelona to provide for necessary urban expansion: a nine square kilometer area between the medieval city and the once surrounding small towns

Three key figures dominate the architecture of modernist Barcelona: Lluís Domènech i Montaner, Josep Puig i Cadafalch and Antoni Gaudí. Affectionately called ‘The Trinity’, their contribution was not only for outstanding architecture but also for the innovative theoretical knowledge they brought to their practice.

The artistic renewal is based on the creative freedom, the simbology and the profusion of details in the decoration. The new architectural concepts are inspired in nature (organic and colorist forms) and movement (curved and asymmetrical shapes). The use of new post-industrial building materials (such as iron structures) coexists with traditional techniques and crafts (such as blacksmith or glassmaker). New solutions of space, light and interior design are born.[6]

Fig. -4 Casa Lleó Morera , Barcelona, Spain
source: google images

Fig. 5 - Casa Batllo', Barcelona, Spain
source: google images
Casa Batllo is where can be founnd the maximum explosion of light and creativity; and this is thanks to the creative freedom that Josep Batllo gave Antoni Gaudí. From the facade to the interior patios and from the noble to the attic floor in Casa Batllo, all the spaces are designed for even and proportional lighting during most of the day. Starting with the exterior, its undulating and colorful way takes observers away from the idea of a heavy facade, while giving a feeling of lightness. This is reinforced by the glow when the sun shines on the glazed ceramic fragments. It is definitely a unique radiance that changes according to the intensity of the sun and the type of light, natural light by day and electricity by night.

6 "Modernist Barcelona," Mercer Hoteles, last modified August 09, 2009, http://www.mercerhoteles.com/en/blog/barcelona-modernista

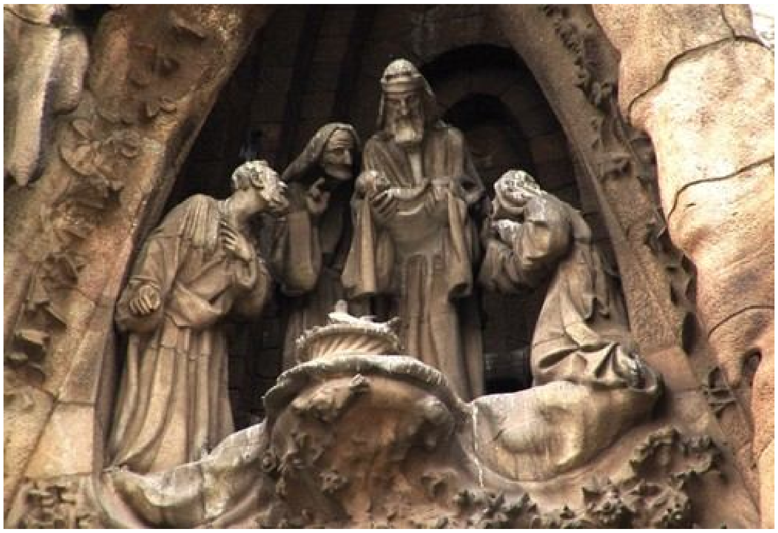


Fig. 6 – La Sagrada familia facade detail
source: google images [accessed in 02/04/2019]

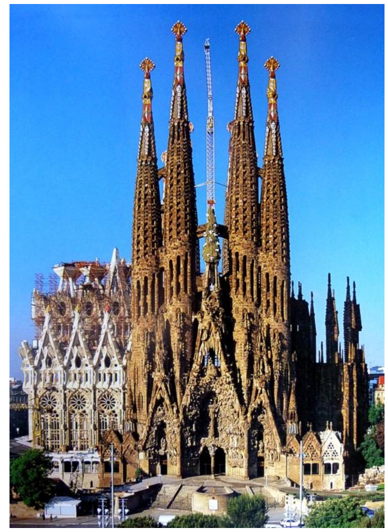


Fig. 7 – La Sagrada familia east facade
sourse: google images [accessed in 02/04/2019]

La Sagrada Familia has its Christ's borning facade oriented to east side. The side where the light provid life and enlightenment.

sourc
02/04

For Gaudí, the perfect light was the Mediterranean light, even claiming: "*The light that reaches maximum harmony is inclined at 45 °, which has no effect on bodies, perpendicularly or horizontally; This light, which is the half-light, gives the most perfect vision of bodies and a more nuanced assessment. This light is the Mediterranean*. " And although at first Gaudí's pieces of work were judged by their extravagant ways, what Gaudí was doing was architecturize nature. For him, the natural environment was the ultimate source of inspiration and education as it was obtained from where the most rational and sustainable existed. An example is the facade of the Casa Mila, curvy, misunderstood and full of nooks and crannies that allow the light to set. A light that casts doubt in the viewer, are we facing an architectural piece of work or a sculpture? It really is a merger as stated by the architect: "*Architecture is the arrangement of light; sculpture is the play on light.* " [7]

7 "The symbolism of light in Gaudi's work." Casa Batlló, last modified February 24, 2015,https://www.casabatllo.es/en/news/the-symbolism-of-light-in-the-work-of-gaudi/

2.1.4 MODERNIST DAYLIGHT

During early Modernism, The Larkin Building built in 1904-19 by Frank Lloyd Wright was noted for many innovations. It w the first known office space to have air conditioning and daylight-filled, four-story atrium formed an inspiring scene workers. Daylight was the primary source of illumination duri office hours. Unfortunately, this `historical daylighting mark was demolished in 1950 to give space to parking.

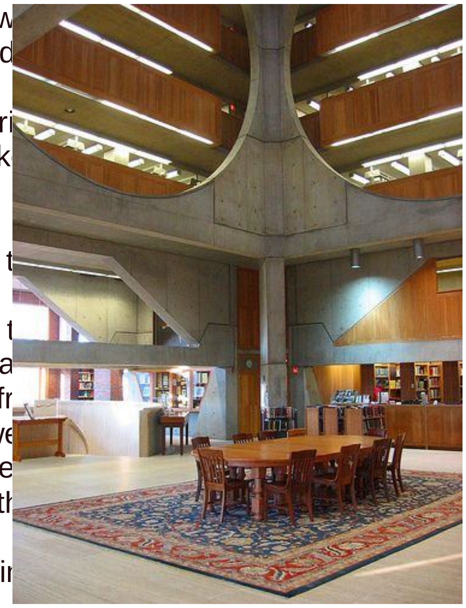


Fig. 9 – *Phillips Exeter Academy Library*, New Hampshire (USA) - Louis Kahn

New industrial processes and serial manufacture opened t scope of young architects to develop new forms contemporary architecture. “Sun, light air and space” was t order; le Corbusier advocated for the detachment of the faca from the supporting construction, which permitted fr positioning of openings in the facade. Horizontal windows we introduced, and with them the possibility to impart comple even illumination of rooms. Louis Kahns' issue, in anoth direction, was the emphasis of mass through structure and work sought to create the mystique of a space and bring it ir life by using the energy of natural light.

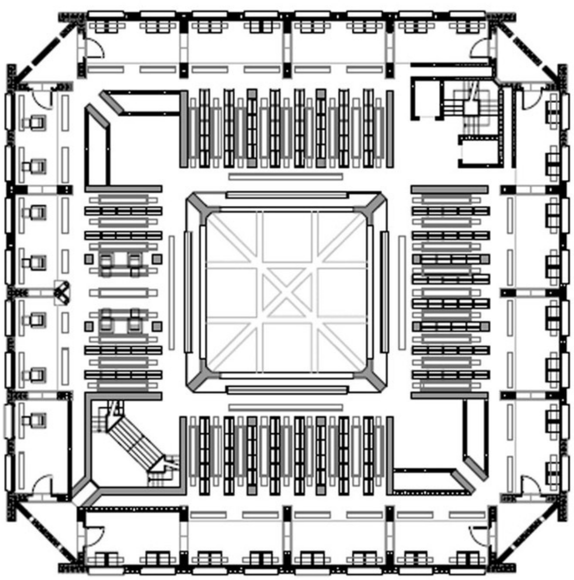


Fig.8 - *Phillips Exeter Academy Library floor plan*, New Hampshire (USA) - Louis Kahn. The concept was that in any floor, the student could take a book and go to read besides the window with natural light.

"A room is not a room without natural light”

Louis I. Kahn

2.1.5 AN EVOLUTIONARY APPROACH TO DESIGN

The concept of evolutionary design reduces waste and resource consumption and supports the changing needs of people, reinforces a sense of history and place, and invites occupants to participate in the life of the building. While design for adaptability and evolution generally focuses on materials, structures, and space planning, it is also possible to apply this concepts of change to daylighting design. Many building types and programs would benefit from greater flexibility and adaptability, including libraries, schools, museums and housing. A surprising number of buildings and programs lend themselves to change. Museums for instance have different luminous and spatial requirements for permanent and travelling collectors. As a result, approaches to space planning, the building envelope, structural systems, and even the role of windows need to be reconsidered.

Daylight can help starting with the term ''reduce, reuse and recycle''. Terms normally associated with waste reduction. Reduce is to use less in the first place. Reuse is to consider ways that buildings can be revitalized to accommodate new needs. This may involve minor or major alterations, however it suggests that the integrity of the original building remains essentially intact. In contrast recycle is a transformative process, where materials or light of the original object is a basis for something new.
(Guzowisk, 1999, p 138)

2.2 NATURAL LIGHT CHARACTERISTICS

2.2.1 CONTRAST AND DIFFUSION

Contrast is the story of light and its counterpart, darkness. The absence of light is as critical to architecture as its presence. Through the relationship between light and dark we are able to determine the form. The degree of light not only informs the way we see but also the mood and expression of our environment. (Major, 2005, p 39)

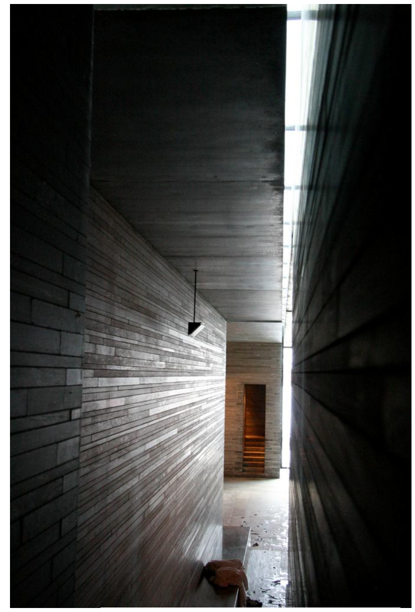


Fig.11 - Therme Vals, Switzerland by Peter Zumthor - Contrasting light
Image © Henry Plummer 2000
Source: Google images

Fig. 10 - Sahra Hospital, Salvador - Bahia - Brazil. Roof Shed in a Curved shape to diffuse daylight
source: Google images

Having dealt with light quantity, consideration must be given to the quality of light, the difference between diffuse light and directed light being one of the most important aspects. We are familiar with these different forms of light through our everyday experience with daylight – *direct sunlight* when the sky is clear and *diffuse light* when the sky is overcast.

Diffuse light is produced by extensive areas that emit light. These may be extensive, flat surfaces, such as the sky in the day-time, or, in the field of artificial lighting, luminous ceilings. In interior spaces diffuse light can also be reflected from illuminated ceilings and walls.

2.2.2 SURFACE, TRANSPARENCY AND REFLECTIONS

The manner in which surfaces are rendered by light reveals their very nature. Appearance is governed by the angle and direction of the light as well as the nature of the surface. We can refer to the appearance of a surface as its texture. All materials have texture.
whether polished and light reflective or roughly the light scattering. Light constrains texture to vary in degrees; where a material transmits light, its internal structure reveals the presence or absence of texture. can be illuminated to show degrees of smoothness, coarseness, grain, consistency, weave or elasticity. They can also be transparent, translucent, refractive or reflective

Fig. 12 - The light reveals texture of the walls
source: Google images

A transparent surface may be clear or reflective depending on the nature of the material and its form. The amount of light behind or in front of it and the most important, how the eyes focus on it.

Fig.13 - Le cols Hotel, Girona - Spain
The use of reflection was explored in this project.
source: Google images

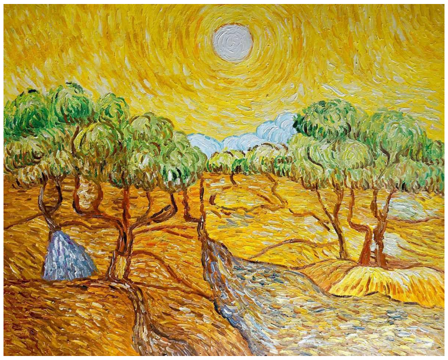
The surfaces of a building might also be considered as sources in their own right. If they scatter light such a white painted wall, then the result will be soft and diffused. If they reflect light very precisely like a mirror or polished stainless steel, then they act as a second illumination point. If they absorb light, like a dark granite floor, they limit the amount of reflection within the space. In some cases the surface can emit light. This introduce the composition of possibilities of opacity, transparence and translucency, the principles of transmission to provide texture.(Major,2005, p 83)

2.2.3 COLOR

throughout the day natural light varies its color temperature. Early mornings the color temperature are about 8000^0 kelvins with tones of blue. Late afternoon the temperature is about 3000^0 with a orange color, it's called " the golden hour ". But the light colors inside a room can be modified by reflecting on painted surfaces and materials to achieve psychological atmospheres and sensorial perceptions.

Fig.15 - Water temple, Japan - tadao Ando
source: Google images

“Any work of architecture which does not express serenity is a mistake.” So said architect and color pioneer Luis Barragán, whose buildings in Mexico have been hugely influential not just on other Modernist architects but also in the way color is used within buildings. Originally trained as an engineer, the influence of the work of Le Corbusier, who he met on a trip to Europe, is obvious in the houses he created on his return home. However his style evolved to suit his surroundings, characterized by playful, bold use of color, drawn from the exterior spaces to the interior spaces of his buildings, as well as soft, concealed lighting which creates a calm, spiritual feel too.



Fig, 16 - Olive trees with yellow sky - Vincent van Gogh
source: https://www.overstockart.com/painting/olive-trees-with-yellow-sun-and-sky [accessed 19/05/2019]

Fig. 14 - Luis Barragan
source:https://thechromologist.com/living-colour-homes-luis-barragan/ [accessed 19/05/2019]

2.3 DAYLIGHT SUSTAINABLE DESIGN

The development of technology that has enabled us to build openings into the roof and walls of a structure has advanced over time. Glass was first developed by the Egyptians as early as 3000 BC, but it was not used to fill an opening in a building until much later, during the first century BC in Imperial Rome, when small panes of glass were used to simultaneously admit the warmth of sunlight indoors while protecting building occupants from the elements. During the medieval Gothic period, small panes of stained glass were used in cathedral architecture, and new innovative window frames and buttresses supported these small panes all the way up to the roofs, which continued to grow in height.

It was not until the seventeenth century AD in England that large panes of glass were manufactured and installed in buildings. During England's industrial revolution, glass walls and wrap-around windows at the corners of buildings were used to achieve higher levels of light in workplaces, but eventually the pressure for a more economical use of space led to the lowering of roof heights and the reduced penetration of daylight within buildings.

Utility companies and electrical lighting manufacturers took advantage of this and encouraged the widespread use of light bulbs throughout the 19th and 20th century. By the 1960s, it was believed that artificial, electrical light ought to become the sole source of illumination, and the need for high quality interior lighting made electrical lamps appear to be an inevitable necessity. Daylighting was no longer seen as a functional technique for indoor lighting, and new, windowless factories and schools were constructed.

The energy crisis of the 1970s motivated people to find new approaches to lighting that did not strain the already limited and irreplaceable supply of fossil fuels. Since then, manufacturers of daylighting devices re-entered the field of mainstream lighting, and have increased production to accommodate the growing need for cost-efficient, natural light sources. While daylighting is not cost-free, since it can lead to heat gain and loss as well as further issues that necessitate the use of controls for glare and ventilation, there are significant savings that result from the use of sustainable daylighting devices

Passive architecture, which relies on the natural environment for lighting, heating, and cooling, and which reduces the need for artificial lighting and air conditioning

Relative spectral sensitivity

Group	Material samples	in %
sensitive	oil paints on canvas	100
very sensitive	textile samples	300
	watercolour paints on hand-made paper	485

The relative spectral sensitivity of the materials shown here is based on the impact on oil paintings (reference value: 100 percent). So watercolours, at 485 percent, are nearly five times more at risk than an oil painting. The illuminance on the object is 200 lux – a compromise between the brightness needed for the visual task and the conditions required for conservation; the illuminance on very sensitive objects should not exceed 50 lux.

Fig. 16a - Relative spectral sensitivity

Source: Good lighting for Museums, galleries and exhibitions. Fordergemainshaft gutes Licht. Available at www.all-about-light.org

Relative damage potential of light sources

Light source	without	edge filter, filter edge at λ (nm): 380	400	420	window glass: simple	double
	in %					
Daylight	235	155	130	110	205	190
General service tungsten filament lamp	85	75	70	65	80	75
LV halogen lamp	100	80	75	70	90	90
High pressure metal halide lamp	220	175	145	110	210	210
Fluorescent lamp, neutral white	100	85	80	70	95	90
Fluorescent lamp, warm white	90	75	70	60	85	85
LED, cold white	80	80	80	75	80	80

The relative damage potential of daylight and the lamps listed here is based on the impact of unfiltered light from low-voltage halogen lamps (reference value: 100 percent). An object exposed to the light of a metal halide lamp with a 380 nm edge filter for 1,000 hours at 200 lux illuminance, for example, sustains nearly twice as much damage (180 %) as a similar object exposed to an unfiltered low-voltage halogen lamp.

Fig. 16b - Relative damage potential of light sources

Source: Good lighting for Museums, galleries and exhibitions. Fordergemainshaft gutes Licht. Available at www.all-about-light.org systems, has become one of the leading trends in sustainable design. New innovations in passive architecture harness natural and renewable resources in a way that balances the benefits for present-day building occupants with the needs of future generations. Daylighting has become more sophisticated than simple openings in a building structure. New materials and technologies have led to advances in design, which can enhance or control interior light levels through the use of GPS units, specialized lens coatings, photovoltaic energy, mirrors, and blind systems.

Another relevant aspect is the search for energy efficiency in the built environment. The economy in the use of artificial systems of lighting needs to be one of the premises of a more efficient project and the use of natural light is the first strategy to be considered. According to Corbella, "If the lighting project is well designed, it will result in a great saving of electric power, both in artificial lighting and in air conditioning. Remember that all the electric energy used to illuminate converts to thermal energy at the end of the transformation process, which contributes to increase the internal temperature". The optimized use of natural lighting, whether zenith or coming through the glass façades and windows, contributes to the conservation of energy in buildings by avoiding the use of artificial lighting unnecessarily and to favoring the visual perception, raising the project from the point of the view of design quality. According to Acselrad , one of the discursive matrices of sustainability is self-sufficiency, which is related to the proposals for preservation and construction of self-sustaining conditions. [8]

A bioregional approach to daylighting concerns the ways that design can grow from, respond to, engage in, and benefit from the life forces of a specific region. The track of the sun, the conditions of the sky, the climate, and the nature of the site are significant bioregional forces that influence daylight [9]

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8 Esteves, Ana Paula. Caetano,S.Diego and Louise M. B. Lomardo. "The Importance of Zenithal Lighting System for Natural Light Gains and for Local Energy Generation in Brazil." *World Academy of Science, Engineering and Technology International Journal of Urban and Civil Engineering* Vol:12, No:6 (2018): 682, http://waset.org/publication

9 Mary Guzowski, *Daylighting for Sustainable Design* (New York: Mcgraw-Hill, 1999) 170.

2.3.1 FORM AND LUMINOUS PROGRAM

On the topic of architectural form, Louis Kahn suggests : "I think of form as a realization of nature, made up of inseparable elements. Form precedes design. It guides its direction for it holds the relation of its elements".
Before explore forms that will best realize lighting design objectives, it is necessary to develop design criteria. How much light is needed ? Where should it be located ? What seasonal and climatic issues have to be addressed ? quality and quantitative daylight criteria might include luminance levels (target foot-candle values of daylight factors based on program, tasks, and the desired quality of light), light distribution, quality of light (direct, indirect light, luminous characteristics), diurnal and seasonal luminous needs and concerns, shading requirements and profile angles, window orientation, human comfort, glare control, contrast ratio, The criteria can be used to inform the design process and to clarify the specific opportunities and constraints of given projects. the more explicit the daylight objectives, the easier it will be to determine appropriate natural light forms. After the luminous program is defined, the designer can begin to explore its relationships to form. [10]

10 Guzowski, *Daylighting for Sustainable Desi*gn, 176

2.4 NATURAL LIGHT FOR ART EXHIBITION SPACES

The consideration of natural light use into art space projects have some points to be discussed where some theories have some different agreements. For instance some positive points that defend its use relies in the fact that most of the ancient artwork were created with natural light and were during centuries exposed to it. So its natural and rhetorical to keep using it. Other point is that daylight variation and external view entertain the public during their experience into the art gallery or museum. Also Artificial light releases CO2, so it's more sustainable and reasonable to use sunlight.
Connecting outside make people feel good and the building integrated to surroundings improving the quality of the visitor experience. Daylight allows people to have the sense of time change and connection to outside world. in this sense the exhibition space has no intention to isolate the observer from the real world and locate art in a closed box trying to create a parallel atmosphere where the art would express itself.

It has economic benefits once it diminishes the use of electricity when it should be used when the weather changes the appropriate conditions to daylight or in specific times when natural light are not available. Other aspect is that daylight has full color spectrum to show the original appearance of the objects and artwork and better color render to the objects to be closed observed.

In terms of disadvantages it is pointed that daylight is difficult to control, which is partly true. It has a huge variation throughout the day and the seasons of the year depending on the location. But with some methods of control and monitoring it is manageable and very satisfying. It has UV radiation, which is not good for artwork, but there are a lot of options to use UV filters in the windows. Poorly conceived daylight generates degradation, high costs and increase glare but with planning this can be solved.

Fig. 16 - Beach, morning light - by sorolla, the light painter
source: https://santhatela.com.br/joaquin-sorolla/sorolla-praia-luz-manha/
[accessed 30/05/2019]

Fig. 16a - Miro Foundation - Barcelona, Spain. In this case side light was diffused by translucid curtains and reflected by the rounded forms in the ceiling.
source: by the author

Fig. 16b - Miro Foundation - Barcelona, Spain. Natural side light was used to illuminate the sculptures into the gallery
source: by the author

2.5 NATURAL LIGHTING CONTROL ELEMENTS IN EXHIBITION SPACES

2.5.1 SKYLIGHTS / TOPLIGHTS

The diversity of shapes and sizes can make this kind of option illuminate any kind of space. It started to be used with the necessity to increase the level of luminosity into a space where the side windows where no more sufficient.

"La luz cenital es la que viene de lo alto, sea de una ventana situada en la parte alta de un muro, sea de una abertura en la cubierta que ilumina un espacio interior o que puede considerarse próximo a un interior.

El tamaño y posición de las ventanas establece el grado y tipo de comunicación y de dialogo entre el interior y el espacio exterior, sea este urbano o natural. Se trata de un sistema de relaciones que la fachada se encarga de expresar.

En la posición normal, de pie o sentadas, miramos horizontalmente. La posición acostada nos hace mirar al cielo, pero entonces acostumbrados a estar dormidos y con los ojos cerrados. La luz que viene desde lo alto, cuando el sol está en el cenit, no se puede mirar debido a su intensidad.

Con la luz cenital, los espacios interiores disponen de una atmosfera luminosa privada e independiente. La luz desciende hacia el suelo con la ayuda de la forma y el relieve del espacio interior o sin ellos. Las aberturas en la cubierta construyen una fachada oculta que esta a servicio exclusivo de la luz.

El espacio interior sin aberturas en los muros verticales y iluminado desde lo alto convierte al exterior en una realidad ajena. es entonces cuando se pasa de una relación de visión-iluminación a una de solamente iluminación, en la que, además, a veces se oculta la fuente luminosa. Las aberturas en la cubierta proponen una relación abstracta con el exterior, casi irreal, enigmática, secreta, protegida."[11]

Fig. 17 - Pantheon, Rome - Italy
source: google images
The light falls from the great 8.9 m in diameter central hole (oculus) in the top of the dome, emphasizing the curve of the roof through a play of light and shadow. Light travels 43 meters to symbolize the connection of heaven with the earthly world. The interior conveys a sense of grandeur and harmony. It represents a classical light and works as a solar clock.

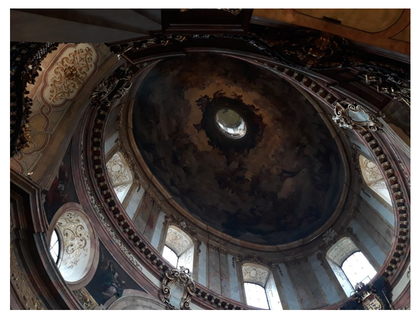

Fig. 18 - Zenithal light - Stephandom, Vienna. The light is directed trough the thick walls to light the paintings uniformly.
source: by the author

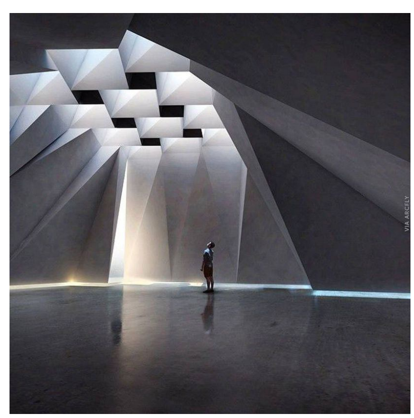

Fig. 19 - Contemporary Zenithal light - The main purpose of the light is to create an emotional state
source: Google images

11 Elias Torres," Luz Cenital," *(Phd diss, Universitat Politècnica de Catalunya,1993*): 15

2.5.2 SIDE WINDOWS

"La vision del exterior desde los edificios es habitualmente horizontal, la del horizonte, y, por lo tanto, paralela al suelo y perpendicular a las fachadas. Se mira a traves de aberturas situadas en el plano vertical, las puertas y las ventanas. Las fachadas de los edificios dan forma a la ciudad. Son también las superficies que comunican y separan lo público de lo privado". [12]

The design and form of the windows are the first considerations. It's size, position, sectional characteristics, and relationship to other surfaces ultimately define the luminous experiences within a space. they can be spaces in and of themselves, stages for activity, filters to the h outside, frames for views, and much more. Concerns are about size, location and detailing.

Atemption is often paid to the size of windows (or glazing area) because of the impact of glazing on energy consumption. the size and its influence on daylighting must also be considered from a broader conceptual perspective which might include the connection to the site, desired quality or mood of the light, human comfort, articulation of form and visual relief

In order to develop a window it must be considered the how much light is needed, how the levels of illumination is appropriate, the need of light distribution, the distribution has to be uniform or if there are areas that have greater or less needs for daylight. Also if there is a particular mood or character that is appropriate for the program. What is the role of light and shadows ? Based on this type of requirements, the designer can begin to assess the relationship between the size of aperture and the luminous program.

Small windows typically create distinct pools of daylight that punctuate a space with rhythms of light and shadow. Also defines a boundary between the inside and outside which is accentuated by the contrast between the mass of the wall and the small area of glazing. As the size of the window increases there is a correspondent decrease in both the contrast of light and shadow and the boundary between inside and outside. Small window frame some specific view and large ones creates a less discriminating boundary washing the room surface with light. Good daylighting does not requires large windows.

Fig. 20 - Sahara west library and museum. Different forms and shapes of side windows
source: https://knpr.org/desert-companion/2018-08/architecture-more-books

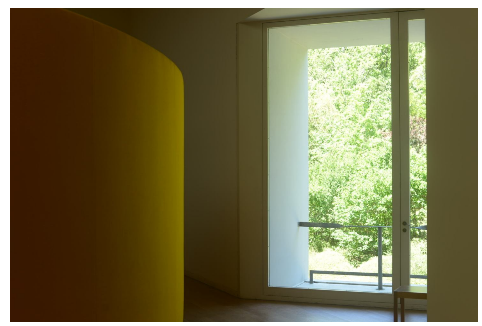

Fig. 20a - Serralves Foundation - Porto, Portugal. The side opening brings light to floor level and promote exterior interaction

source: by the author

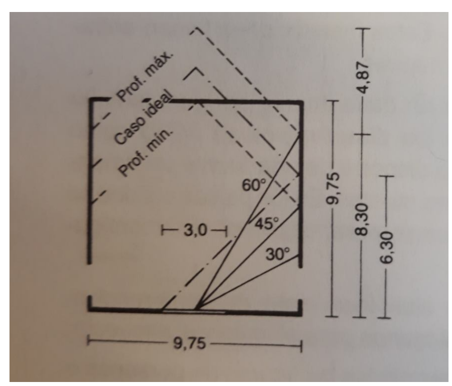

Fig. 20b - Floor plan. Exhibition space with lateral natural light. Surface for exposition between 30° and 60°, room-high of 6.7 meters

source: Neufert, A arte de projetar em Arquitetura, Pg 109.

12 Torres, "Luz Cenital," 22

In order to use daylight more effectively it is critical to put light where it is needed. This approach minimize problems with visual and thermal comfort and helps to avoid the creation of monotonous luminous environment that results over illumination.[13]

The position of the window on a wall or ceiling affects how light will be distributed and what relationship it will have with the tasks, activities and experiences in space. Low windows for example, provide an opportunity to take advantage from the ground-reflected light, which can be redirected from exterior surfaces and floors to bring light deep within the space (assuming that light colored surfaces are used and that floor is not covered with objects). Low window provide direct contact to landscape. Mid-height window are popular to combine views, reflected light and optimal location for ventilation in proximity to the occupant. as the window rises, so does privacy. High windows shift the visual relationship from earth to sky, while allowing light to penetrate deep into the space. In this case the surface bellow the window may be cast in shadow that can creates excessive contrast between the wall and window. To solve this a bilateral illumination can be used.[14]

Fig. 21 - Aaalto's Seinajoki library - bilateral illumination to provide adequate light inside and capture daylight from different positions of the sun throughout the day

source:http://arqbibliotecas.blogspot.com/2010/11/biblioteca-en-el-centro-civico-de.html[acessed 15/04/2019]

2.5.3 REFLECTED LIGHT

2.5.3.1 CLERESTOIRES

Celestoires is a high section of wall that contains windows above eye level. The purpose is to admit light, fresh air, or both.

The use of clerestories—a row of windows well above eye level—stretches all the way back to temples in ancient Egypt. Since then, they've been a favorite feature in religious structures for their ability to flood vast spaces with natural light, creating interior environments so open and bright they can feel downright heavenly. Today, the architectural feature is employed in modern homes for exactly the same reason, although extra sunlight isn't the only benefit. Whereas lower windows can let in sun in a direct and sometimes harsh way, a row of windows up high lets in a more ambient light.

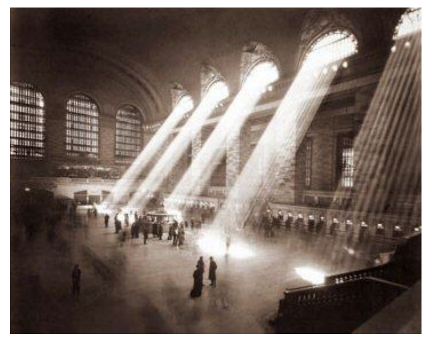

Fig. 22 - Train station clerestoires

source: Google images search

Fig. 23 - House clerestoire

source: Google images search

13 Guzowski, *Daylighting for Sustainable Design*, 224
14 Guzowski, *Daylighting for Sustainable Design,* 231

2.5.3.2 LIGHT SHED

The design of zenith elements must be done respecting the local solar trajectories, so that there is no direct solar radiation. Thus, the sheds should be designed with south orientation (south hemisphere) and in order to obtain a mask in the solar trajectory diagram that hides all trajectories. The sheds facing the South can not only favor the access of indirect natural light, which does not prevent unwanted heating, but also allows the generation of energy directed to the North, a more favorable orientation for the reception of solar radiation directly on the photovoltaic panels.

Fig. 24 - Light shed. Waterside Buddist Shrine, Tangshan, Hebei,China

source: https://www.archdaily.com.br/br/872594/a-luz-zenital-como-solucao-de-iluminacao-natural-em-16-projetos

The face to the North can be an opaque material that receives the traditional modules or can be semi-transparent photovoltaic modules. This partial transparency is obtained from so-called photovoltaic films and can also be interesting applications in atrium buildings with solar light. It should be emphasized that the North orientation will receive the greatest heat heating load by direct solar radiation throughout the days of the year (southern hemisphere), which will require an energy analysis before its specification to avoid undue overheating.

In addition, the slope of the North face of the shed that intends to generate energy should follow the slope of a module at an angle equal to the local latitude and oriented to the north (in the Southern Hemisphere) making possible the greater use of solar energy, this is caused by the slope of the Earth's axis in relation to the solar orbit. In this way, the shed can become an important element in the photovoltaic integration in the building, because it brings together energy efficiency and natural light of quality.

Fig. 25 - Light shed.

source: https://scalescenes.com/product/r021b-north-light-engine-shed/

[accessed 01/06/2019]

2.5.3.3 LIGHT SHELVES

A light shelf is a horizontal surface that reflects daylight deep into a building. Light shelves are placed above eye-level and have high-reflectance upper surfaces, which reflect daylight onto the ceiling and deeper into the space. They are typically used in high-rise and low-rise office buildings, as well as institutional buildings. This design is generally used on the equator-facing side of the building, which is where maximum sunlight is found, and as a result is most effective. Not only do light shelves allow light to penetrate through the building, they are also designed to shade near the windows, due to the overhang of the shelf, and help reduce window glare. Exterior shelves are generally more effective shading devices than interior shelves. A combination of exterior and interior shelves will work best in providing an even illumination gradient.

Fig. 27 - Exterior part of Light shelves
source: https://www.google.com/search?q=light+shelf&source=lnms&tbm=isch&sa=X&ved=0ahUKEwingNy6_JPjAhVgHLkGHc6iDA8Q_AUIECgB&biw=1093&bih=526#imgrc=D04xfZq-P1Wa2M:
[accessed 01/06/2019]

Light shelves make sunlight penetrate the space up to 2.5 times the distance between the floor and the top of the window. Today, advanced light shelf technology makes it possible to increase the distance up to 4 times.

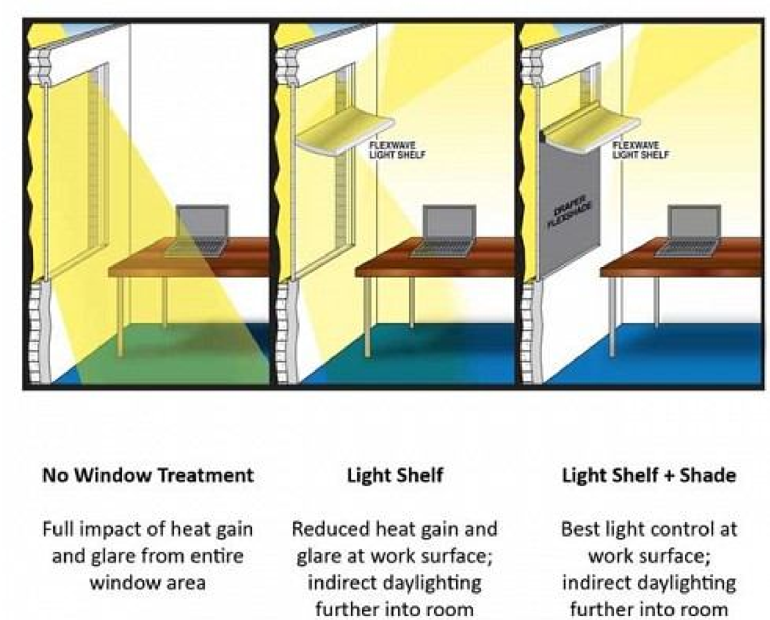

Fig. 26 - Light shelves response to daylight
source: https://www.amshades.com/category/12/light-shelves
[accessed 02/06/2019]

2.5.4 GLAZED SKIN

Today, glazing systems are manufactured to transmit an adequate amount of visible light while minimizing heat gain. However glazed skin can be an aesthetic element with the function of bringing light to the building interior, when browsing glass products for exterior applications, manufacturers will offer several values that will help professionals to parse out a particular product's thermal performance. Here are a few examples:

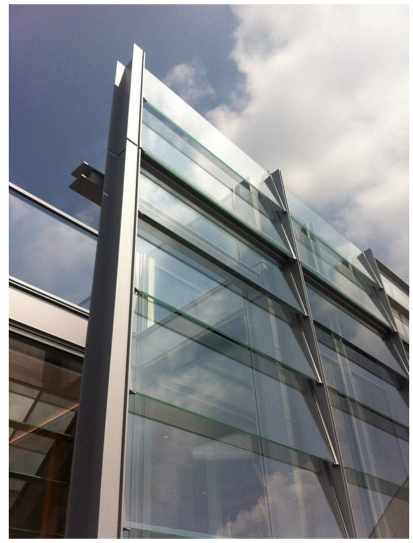

Fig. 28 – Glazed skyn
source
:https://www.metalarchitecture.com/articles/dual-skin-fa%C3%A7ades
[accessed 03/06/2019]

- **Low-E Glass:** Low-E glass has a microscopically thin, transparent coating that reflects long-wave infrared energy and thus has lower emissivity. This thermally reflective material reflects both heated and cooled air back into the interior of a building, rather than allowing it to flow out.
- **Solar Heat Gain Coefficient (SHGC):** The SHGC is the fraction of solar radiation that is admitted through a glazed façade or more traditionally, window panes. The SHGC is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits.
- **Visual Light Transmittance (VLT):** VLT is the percentage of transmitted visual light that passes through the glazing. When good daylighting is important, a higher VLT is desirable.
- **Building Integrated Photovoltaics (BIPV):** BIPV are an increasingly popular approach for using the building skin as a means to harvest solar energy. Leading manufacturers of photovoltaic glass include Onix solar and PolySolar.[15]

15 ''How to Specify: Glazed Façade'', last modified April 20, 2019,Architizer,https://architizer.com/blog/practice/details/specify-glazed-facades/

2.5.5 LOUVERS

Fig. 29 – Fondation Beyeler, Basel, Switzerland – External automated roof louvers

source:https://www.erco.com/projects/culture/fondation-beyeler-1352/en/

A louver (American English) or louvre (British English) is a window blind or shutter with horizontal slats that are angled to admit light and air, but to keep out rain and direct sunshine. The angle of the slats may be adjustable, usually in blinds and windows, or fixed.

Modern louvers are often made of aluminum, metal, wood, or glass. They may be opened and closed with a metal lever, pulleys, or through motorized operators. The Standard specifies requirements for the construction of buildings using louver in bushfire-prone areas in order to improve their resistance to bushfire attack from burning embers, radiant heat, flame contact and combinations of the three attack forms. Diffused daylighting creates uniform and consistent lighting, and helps ensure that daylight is a primary source of illumination. One of the most effective ways to manage solar heat gain and sunlight is integrated louvers - hermetically sealed glass units combining louvers within glass for exterior glazing applications.
Integrated operable louvers typically deliver flexible heat and light control, and manage the quantity and quality of light transmission through fenestration. Motorized louvers or sunblades can provide maximum daylight control. The best daylighting and privacy results can be achieved by installing windows with advanced louvered glazing technologies. Eliminating strings and cords ensures lifetime alignment and zero maintenance.

Fig. 30 – Horizontal louvers

source:

https://www.alproaluminum.com/products/louver-and-sunshade/

[accessed 01/06/2019]

Indoor lighting preferences can be controlled by adjusting integrated louvers. Fully open and maximum daylight will penetrate; angled up and light will reflect off ceilings creating a diffused effect; fully closed and light blockage and complete privacy can be achieved.

Integrated louvers typically feature precise control mechanisms that can rotate 180 degrees horizontally or vertically to distribute and diffuse light with simple louver rotation. They can filter sunlight for thermal and human benefits, or reflect light back outside to block UV rays, unwanted glare and solar heat gain.

Specifically, louver positioning can block solar heat gain while still filtering daylight into interiors. Blocking solar heat gain through glazing guarantees an optimal Solar

Heat Gain Coefficient (SHGC); utilizing integrated louvers ensures simultaneous transparency options. In the summer, adjustable integrated louvers can block direct sun light to significantly reduce cooling requirements. In the winter, integrated louvers can be angled parallel to the sun rays to leverage solar energy for interior heating. Integrated louvers therefore offer variable SHGC that can be adjusted according to seasonal requirements.

When installed in exterior applications, integrated louvers can significantly reduce energy consumption in support of LEED® requirements.[16]

2.5.6 BLINDS

Blinds and shading are elements located outside or inside the windows to block completely sunlight or partially. Some examples are curtain textiles, awning blinders, roller shutters. Some of this elements can have perforations and some level of transparency allowing outside view.

Fig. 31 – Automated internal blinds

source:

https://www.niceforyou.com/en/blinds [accessed 15/04/2019]

2.5.7 LIGHT SENSORS

Control elements can work manually or in a passive way integrated with architecture without spend any cost related to energy. But some automated light control system can make adjusts at real time according to sunlight changes throughout the day and seasons without much more costs with electricity bill. The automatization gives independency and quick answers that better controls light. There are a lot sensors in the market that can read daylight and move louvers, blinders and openings and adjust the level of artificial light compensating lack of natural light. Some museums use this strategy in their galleries in order to control light and temperature both for artwork and visitors.

16 https://www.buildings.com/buzz/buildings-buzz/entryid/440/using-integrated-louvers-for-optimal-daylight-and-energy-management [accessed in 18/03/2019]

2.6 LIGHTING SPACE'S ATMOSPHERE

Undoubtly the nuances of light bring us an state of emotion and serenity. It's not by accident that temples, churches or spiritual spaces take it into consideration so deeply. Light can inspire peace, tranquility, attention, agitation, among so many others sensations and perceptions created by the lighting atmosphere.

We must add, though, that the holistic perception of atmospheric feelings in the pre-dimensional space has much in common with the vital involuntary experiences that (always) lead to adequate semi-automatic reactions. Like a driver avoiding a danger by corporeally using the optic channel (the look forwards, sideways and backwards, thanks to rearview mirrors) and the tactile-vibratory channel (hands, feet and torso), a person who lives an atmospheric feeling knows immediately how to behave: 'he who is content can jump around; he who is sad can moan and sit dull or as if he was shattered; he who is ashamed can lower his head, shrug his shoulders; he who is irremediably desperate can burst into a clamorous laughter, etc.: no one that is thus involved has to awkwardly wonder how it is done' (Schmitz 1990: 305). [17]

At the centre of our (aesthetic and phenomenological) interest there is, therefore, atmosphere – and here is a first, approximate, definition – as a qualitative-sentimental prius, spatially poured out, of our sensible encounter with the world. Something that is 'chronologically at the start and objectively at the peak of the hierarchy', as emerges from the fact that 'the sensibility to the differences in way-of-being or "atmosphere" existing between two colours is normally greater than the sensibility for the corresponding differences between pure chromatic qualities' (Metzger 1941: 86). Perceiving an atmosphere, therefore, means grasping a feeling in the surrounding space, definitively the most important thing for men, implied by any subsequent clarification, both sensible and cognitive. It means being gripped by a something- more, and it is precisely 'this something-more, exceeding real factuality and which nonetheless we feel with and in it, that we can

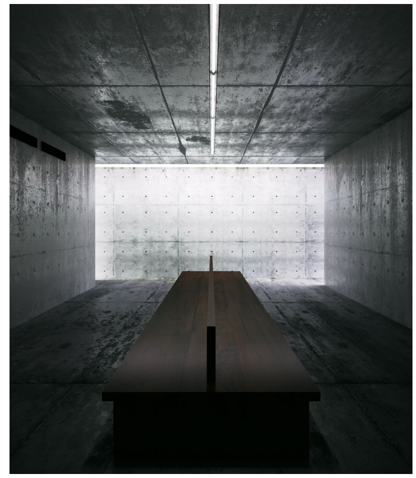

Fig.32 – Chichu Art Museum, Japan – Tadao Ando. Chichu Art Museum was constructed in 2004 as a site rethinking the relationship between nature and people. The museum was built mostly underground to avoid affecting the beautiful natural scenery of the Seto Inland sea. Artworks by Claude Monet, James Turrell, and Walter De Maria are on permanent display in this building designed by Tadao Ando. Despite being primarily subterranean, the museum lets in an abundance of natural light that changes the appearance of the artworks and the ambience of the space itself with the passage of time, throughout the day and all along the four seasons of the year. This project has a great emotional appeal and natural light works changing the space's atmosphere in the galleries.

source: http://www.cgarchitect.com/2014/08/chichu-art-museum-tadao-ando [accessed 15/04/2019]

17 Tonino Griffero, *Atmospheres:Aesthetics of Emotional Spaces* (USA: Ashgate Publishing Limited, 2010),17.

call “atmospheric”’ (Tellenbach 1968: 47), seeing in it an excess with respect to the place and, if you like, a great part of what ‘resists a “representational” attitude’ (Franzini 2006: 72).[18]

It's important to mention that the light perception we have from a space depends on emotional factors and our sensitivity. Actually we do not see the objects itself, we see their reflections brought by light till our eyes. But the interpretation of the world surrounding us will pass through our mental analysis and memory background.

Some definitions of lighting quality in the literature propose including the emotional experience (e.g., Boyce “Good lighting is lighting that allows us to see what we need to see quickly and easily, without discomfort, and which does lift the spirit”) [Boyce 2013].

18 Griffero, *Atmospheres:Aesthetics of Emotional Spac*es, 20

3. Study cases and tools

3.1 KANORIA CENTRE FOR ARTS

Visiting Vitra museum in April 2019, Germany, I was pleasured with the exhibition from the Indian architect Balkrishna Doshi. His concerns about people's well-been and the importance about natural light in his professional projects called my attention leading to a great sustainable design using local materials and natural resources. This fact allied to a similar architectural shape of the building made me choose Kanoria Centre for Arts as one of my study cases.

Fig. 32 – Kanoria Centre for Arts - class rom, Ahmedabad, Gujarat India.

source: https://www.kanoriacentreforarts.org/education [accessed 15/06/2019]

KCA was established in 1984 by our Chairperson Urmila Kanoria with the support of Dr. B. V. Doshi and the Ahmedabad Education Society. Its inaugural stone was laid by the Late M. F. Husain and inputs from Bhupen Khakhar, Piraji Sagara, Geeta Kapur and many more leading personalities in diverse creative fields established KCA's foundation for becoming a non-profit, self sustaining institution.[19]

The institution promotes short and long duration art courses, it has art galleries and spaces that welcome professionals, students and general public.

Fig. 33 - Kanoria Centre for Arts, Ahmedabad, Gujarat India.

source : https://www.kanoriacentreforarts.org/
[accessed 15/06/2019]

19 " Artist Residence Programme". Kanoria Centre for Arts. Last modiied July 07, 2019, https://www.kanoriacentreforarts.org/

Fig. 34 - Kanoria Centre for Arts Model, Vitra Museum, Germany
source : by the author

Fig. 35 - Kanoria Centre for Arts , interior view from roof
source:
https://ravtejsingh.wordpress.com/2015/07/07/kanoria-centre-for-arts/
[accessed 20/06/2019]

The project uses a light shed on roof top to bring down sunlight filtered by a diffused glass extending its edge vertically (fig. 36) The roof also presents a triangular opening that creates an atrium illuminating inside where trees compose the ambiance. Natural lighting is complemented with artificial light (fig. 35)

Fig. 36 - Kanoria Centre for Arts, Ahmedabad, Gujarat India. Exterior view

source: :
https://ravtejsingh.wordpress.com/2015/07/07/kanoria-centre-for-arts/
[accessed 20/06/2019]

3.2 KIMBELL ART MUSEUM

The Kimbell Art Museum's original building, designed by Louis I. Kahn and opened to the public for the first time in 1972, has become a mecca of modern architecture. Kahn designed a building in which "light is the theme." Natural light enters through narrow plexiglass skylights along the top of cycloid barrel vaults and is diffused by wing-shaped pierced-aluminum reflectors that hang below, giving a silvery gleam to the smooth concrete of the vault surfaces and providing a perfect, subtly fluctuating illumination for the works of art.

The main (west) facade of the building consists of three 100-foot bays, each fronted by an open, barrel-vaulted portico, with the central, entrance bay recessed and glazed. The porticos express on the exterior the light-filled vaulted spaces that are the defining feature of the interior, which are five deep behind each of the side porticos and three deep behind the central one. Additionally, three courtyards punctuate the interior space. Though thoroughly modern in its lack of ornament or revivalist detail, the building suggests the grand arches and vaults of Roman architecture, a source of inspiration that Kahn himself acknowledged. The principal materials are concrete, travertine, and white oak.[20]
Kimbell art museum contrast illuminance levels to create a hierarchy in which the artwork predominates. The kimbell is not a fully daylit museum. It uses low level of ambient daylight to illuminate the space and supplemental electric lighting to accentuate the artwork. While its possible to use daylight for illumination during a great portion of a day, it is not uncommon to find this task-ambient approach to lighting museums. Although it is less energy and resource-efficient, the use of daylight for ambient, rather than task, illumination helps to avoid the difficult challenge of getting light to artwork in appropriate levels and without its potentially damaging effects. This approach often uses darkness and contrast as a mean of focusing attention on the artwork. While there are strategies to control the damaging effects of natural light (UV filters, shading devices, rotating the artworks, etc) the exclusive use of daylight maybe inappropriate to some programs, curators and clients. In this cases, a task-ambient approach that combines electric light may be the most feasible strategy.

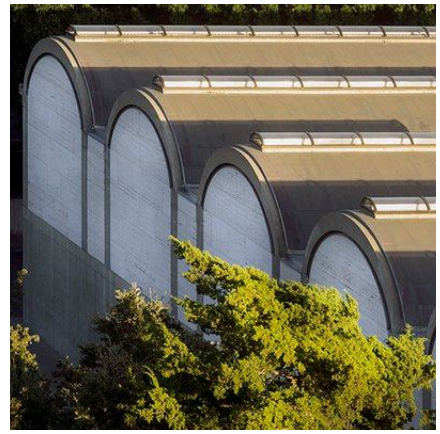

Fig. 37 - kimbell Museum, Fort Worth, TX, EUA. Roof top linear skylight

source: : https://ravtejsingh.wordpress.com/2015/07/07/kanoria-centre-for-arts/
[accessed in 15/05/2019]

Fig. 38 - kimbell Museum, Fort Worth, TX, EUA. Interior roof

source: : https://ravtejsingh.wordpress.com/2015/07/07/kanoria-centre-for-arts/
[accessed in 15/05/2019]

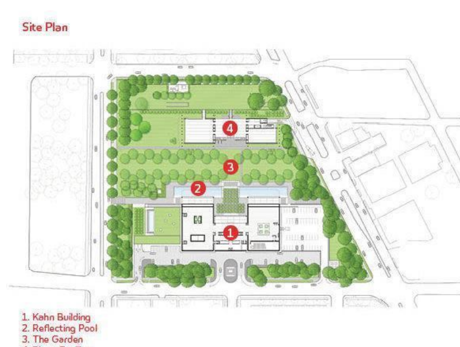

Fig 39. Site plan.
source:
https://www.archlighting.com/projects/structural-light-the-new-renzo-piano-pavilion-at-the-kimbell_o

[accessed in 15/05/2019]

20 "Louis I. Kahn Building." Kimbell Art Museum, last modified August 01, 2019, https://www.kimbellart.org/art-architecture/architecture/kahn-building

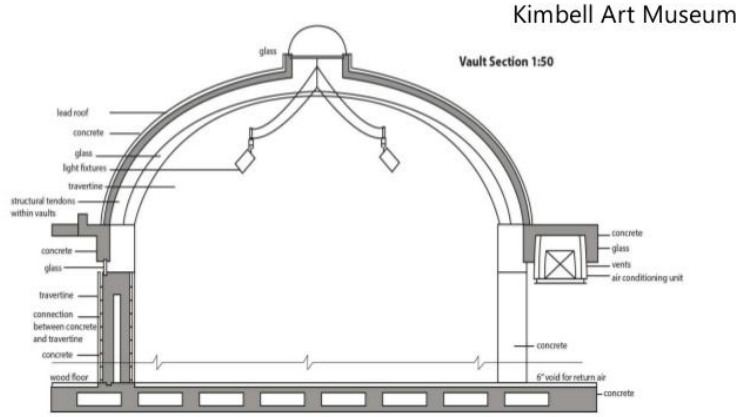

Fig. 39 - kimbell Museum section

source:https://www.slideshare.net/NurjahanBintu/kimbell-art-museum
[accessed in 16/05/2019]

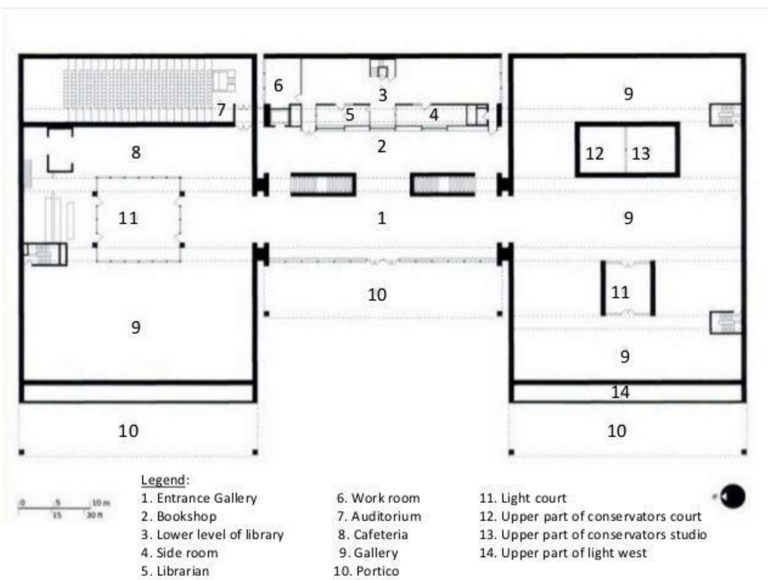

Fig. 40 - kimbell Museum floor plan

source:https://www.slideshare.net/NurjahanBintu/kimbell-art-museum
[accessed in 16/05/2019]

The vault ceilings of the Kimbell Art Museum, often described as “pearly gray”, “moonlit” and, in the words of Kahn himself, “a touch of silver to the room”, are the result of three specific design strategies — the geometry, the material, and the opening through which the light is brought in. But how Kahn prepares the visitors to enter the ‘silent light’ of the museum from the harsh Texas sun outside, by means of a *transition*, is instrumental to appreciate its effect. The design strategy of transition at the Kimbell does two things to prepare the eyes for dark adaptation:

Fig. 33. - sketch of the aluminium reflectors and lit.
Source:
https://medium.com/@priji/looking-at-light-in-the-kimbell-art-museum-3b85f2e3bc62
[accessed in 17/05/2019]

"So this is the kind of invention that comes out of the desire to have natural lighting. Because it is the light the painter used to paint his painting. And artificial light is a static light... and natural light is a light of mood...the painting must reveal itself in a different aspects if the moods of light is included in its viewing... in its seeing. I think that's the nature, really, of a place where you see paintings."

Louis Kahn, *Light is the Theme*

One it reduces the pace of the visitors by means of the *Entrance of Trees* that provides partial respite from the unshaded lawn and increases visual interest by creating patterned light. Second, it also reduces the light levels gradually from the brightly lit outside without shade, to partial shade, and finally full shade of the portico into the 'silver' light of the inside.

The chief source of natural light to the galleries are 2'-6" wide linear roof skylights. From the design's beginning, the roof was planned as a series of parallel channels or half cylinder shapes and these skylight slits were located at the top edges of the spanning shapes. Roof forms were aligned from north to south and the building entrance was located on the west at the edge of a park. This orientation is most efficient for gathering the sun's light though most of its arc and avoids angular differences sun angle differences between summer and winter. This orientation also prevents too much or too little light at the ends of the enclosure when the sun is at the horizon. In the completed design, the west porches shield a narrow strip of horizontal glass above gallery walls from the
setting sun and the museum is not opened until the rising sun has climbed into the sky. Skylights admit natural light to a suspended reflector that, in turn, illuminates the cycloidal concrete gallery ceilings.

The illuminated cycloid ceilings give the museum a life that can't be captured in photographs. The experience of light in the museum derives from its subtle variations. As the positions of sun and clouds change, so changes interior lighting. As visitors move only a few steps, the character of the cycloid surface and the light it reflects also change. The ceilings amplify exterior light variations by concentrating them in the skylight aperture and projecting them onto a concrete surface of great depth and character.

The remaining light sources project stripes of sunlight onto interior surfaces. When the sun is low in the sky, lunette windows and apex skylights project diagonal stripes of light onto travertine faced gallery end walls and the ceiling ends. These thin bands add another changing light pattern to the interior. As the sun sets, sunlight crosses under the entrance porch to create a line of light that advances across the lobby floor and onto the oak doors at the rear of the bookshop. This light is abetted by reflections from pools that line most of the museum's west elevation. [21]

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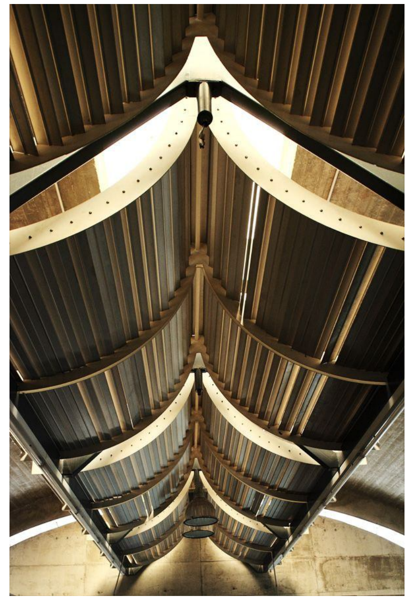
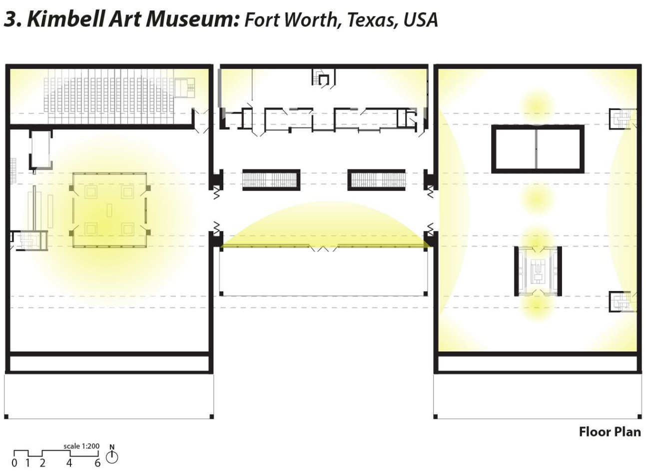
21 Pierce Gifford, " Natural Lighting at the Kimbell Museum." 86th Acsa Annual Meeting And Technology Conference 89. University of Idaho. 2001.

The museum's artificial light comes from incandescent lamps in steel cylindrical fixtures. The cylinders are painted to match the anodized aluminum reflectors and mounted either on tracks mounted on flat ceilings or at the bottom edges of reflectors. Some of these lighting fixtures are low voltage units with adjustable transformers; others are 120 or 150 volt lamps. Bulbs and baffles located at the lower ends of the fixtures provide a range of light beams from a narrow spot to a general flood. A usual method of lighting paintings is to focus lights on the paintings and provide general, less intense lighting for the travertine or linen covered walls. Since the paint surface of some old paintings is not perfect, sometimes lights are adjusted to illuminate only the best portions of the painting. Experiments with haylide lamps prior to construction



Fig, 35 - Perforated reflector detail

source:
https://www.pinterest.com/pin/192599321534905742/
[accessed in 16/05/2019]



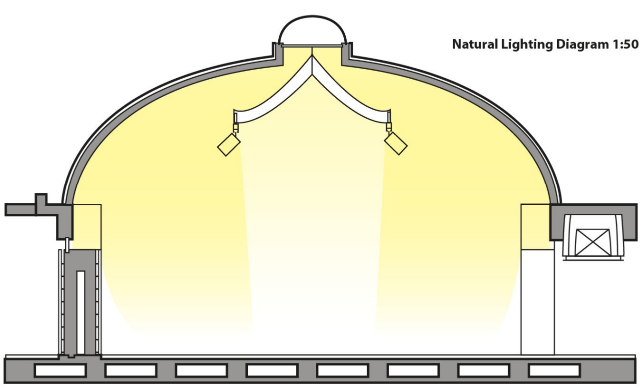


Fig 34. Natural light diagram
Source:
https://www.google.com/search?q=kimbell+museum+site+orientation&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiJ4q7y0pvjAhXxqFkKHcwxCLwQ_AUIECgB&biw=1920&bih=966#imgrc=TZQRIj6QHWR-QM: [accessed in 16/05/2019]

demonstrated that these bulbs provide too white light. The paintings lost warmth under these bulbs and travertine's character was bleached away. There are hobos (sensors) on roof top and on the reflectors that measures sunlight in order to adjust artificial light due to sun variations.

Guzowsky mentions in his book, *Design for sustainable design*, that if we compare sidelight from other buildings and " ...the Kimbel Art Museum, which uses top lighting as primary strategy, we find that the type of daylight strategy employed will depend at a great extent on the overall depth of the building massing. with linear forms designers have the opportunity to admit daylight from multiple facades." The masterpiece projected by Louis Kahn has some light courts to balance skylight with sidelight in order to give a visual relief to the visitors.

Fig. 36 - Light court - Kimbell Art Museum. This strategy brings natural light into the building and promote visual relief to visitors.

Source: https://www.pinterest.pt/pin/512073420121780620/?lp=true
[accessed in 15/05/2019]

3.3 BEYELER FOUNDATION

I visited Beyeler foundation, in Basel, Switzerland, in April 2019 after try to talk to the manager by email unsuccessfully. i got really surprised with the fact that the museum used almost no one artificial light, with the exception of the video projection room. The sky was not clear that day. It's interesting how some museums adopt that daylight concept very well and others like Miro Foundation in Barcelona, which was designed to admit daylight but uses a lot of curtains to block it. To me it makes no sense. By walking through the galleries we can have the view from gardens outside made from huge glass panels. There is a air circulation system that comes from galleries bellow the floor.

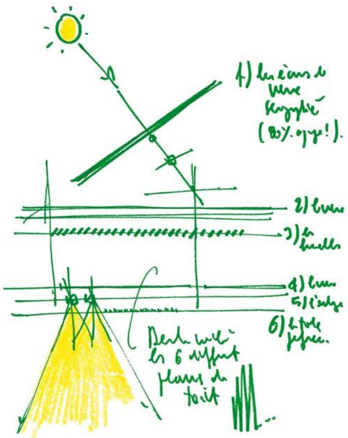


Fig. 38. Renzo Piano drawings. Roof daylight control. source: google images [accessed in 15/05/2019]

Fig. 37. Beyeler Foundation. Frontal facade. The museum has only one fllor where the light aperture is the total roof area created by renzo Piano.
source: https://www.inexhibit.com/mymuseum/fondation-beyeler/
[accessed in 16/05/2019]

Fig. 39. Roof louvers. It's clear here to see the upper fixed inclined fritted glass used to diffuse sunlight and the automated smaller louvers below.

source: https://www.inexhibit.com/mymuseum/fondation-beyeler/
[accessed in 16/05/2019]

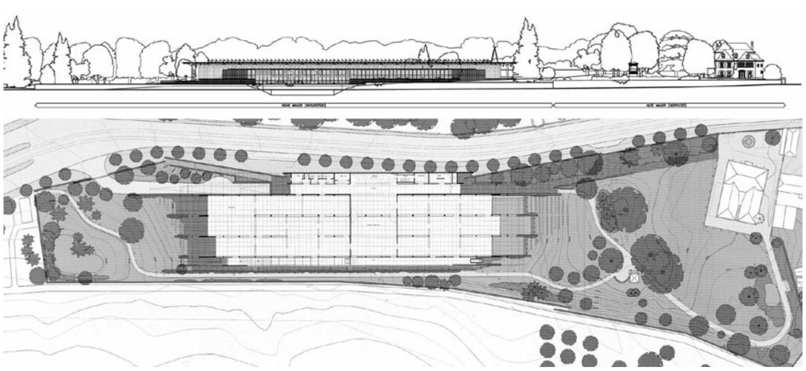


Fig. 37. Beyeler Foundation. Site and section.The longitudinal axis is North-South.
source: https://www.inexhibit.com/mymuseum/fondation-beyeler/
[accessed in 16/05/2019]

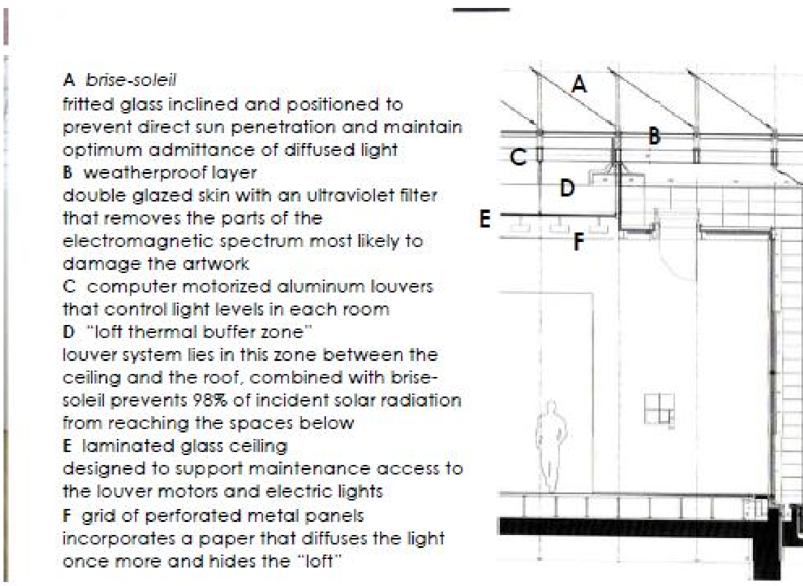


Fig. 41. Interior view from the ceiling - Grid of perforated metal panels.
source: By the author

Fig. 40. Beyeler Foundation. Section of daylighting elements control.
source: Daylighting museum guide,Integrated design lab, Bozeman, MT. Prepared by Chris Hancock, Shelby Hincliff, Justina Hohmann October 6, 2009

It was agreed that daylight should be used as the light source across the whole ground floor, and that the design of the building should seek to maximize the number of hours during which the collection could be viewed by daylight. However, best-practice standards for exposure of works of art to daylight in terms of time, levels, and spectral content could not be compromised by the desire to provide a daylit environment.

Following studies of lighting conditions in Basel, Arup recommended a target daylight factor of 4 percent, which is around double that in most European galleries. An active shading system to control interior light levels within predetermined limits, particularly on bright summer days, was also prescribed as an essential part of the lighting strategy.

These performance requirements were met by the development of a multilayered roof. The outermost element is the layer of fritted glass *brise-soleil* inclined and positioned to prevent direct sun penetration during all museum opening times but also to maintain optimum admittance of diffused light.

Below this lies the weatherproof layer consisting of a double-glazed skin with an ultraviolet filter that removes those parts of the electromagnetic spectrum most likely to damage the paintings to be displayed below.

Immediately below this layer are computer-motorized aluminum louver blades that control light levels in each room of the museum. These levels can be arranged to suit the management of the building and the conservation of the collection. When the museum is closed, for example, the louvers are closed to prevent exposure of artworks to daylight.

The louver system lies in the zone between ceiling and roof, which is designed as a "loft thermal buffer zone" and combines with the exterior *brise-soleil* to prevent 98 percent of incident solar radiation from reaching the gallery spaces below.

The lower boundary of the loft is formed by a laminated-glass ceiling designed to support maintenance access to the louver-blind motors and electric lights in the loft. The electric illumination is designed to complement the daylighting strategy: as daylight fades, triphosphor linear fluorescent fittings gradually compensate, contributing to the maintenance of ideal lighting levels.

The lowest layer in the system forms the visible ceiling of the ground-floor galleries: a grid of perforated metal panels incorporates a paper that diffuses light once more and adds a layer of opacity to the contents of the loft thermal buffer zone. The uniform lighting system is augmented by small low-voltage spotlights positioned on stems at the junctions of each ceiling panel. These can add highlighting and directional light essential for modeling effects of sculpture. [22]

Fig. 42. Exterior north view from glass panel
source: By the author

Fig. 43. West Corredor, winter garden.Thermal buffer spaces extend from the roof sides of the facade, helping to limit the effects of climatic extremes on the building. These buffer zones help to reduce reliance on mechanical systems — particularly important in Switzerland

source: By the author

22 "Architecture Week, " http://www.architectureweek.com/2003/1105/environment_1-2.html accessed May 20, 2019

3.4 CAN FRAMIS MUSEUM

I had the idea to work with the Can Framis Museum in Barcelona during a Master class when I noticed that the institution has the use of natural light as a project concept. Also what was interesting was the fact that the museum was not conceived as an art space. It was an old textile factory that dates backs to the 18th century and was originally owned by the Framis family. I realized that the museum had a lot of to contribute as an study case and an opportunity to me to propose an intervention as I realized that the building was not completely explored in terms of natural lighting use. Afterwards I talked to the museum manager and they gently accepted to work with me allowing light measures and photo registers.

Fig. 44. Can Framis Museum, Barcelona - Spain.
source: https://www.architecturalrecord.com/articles/7495-can-framis-museum?v=preview [accessed in 10/05/2019]

During XIX century (fig. 46), the industrial revolution brought agriculture factories in north Barcelona. The industrial activity in this zone became very important. One of the first factories installed there was the Can Framis textile factory composed by many buildings that occupied a surface equivalent to four Eixample blocks. Some years after with the Cerda urban plan the complex was destroyed by the adjacent streets remaining the chimney and some buildings.

The last restoration was made by the Catalan architect, Jordi Badia, in 2008. I personally interviewed him at his studio BAAS. He told me that the museum restoration was made by a warehouse concept, where initially the artwork exposition was not the main purpose. The natural

Fig. 45. Cam Framis factory before restoration, Barcelona - Spain
source:
https://www.publicspace.org/es/web/guest/obras/-/project/f062-gardens-of-the-can-framis-museum

Fig. 46. Cam Framis complex, XIX century, Barcelona - Spain

source:
https://www.publicspace.org/es/web/guest/obras/-/project/f062-gardens-of-the-can-framis-museum [accessed 10/05/2019]

light use was limited by original structures and the museum direction did not allowed roof openings among other restrictions to prevent artwork damage. It was allowed natural light mainly in the transit areas. Other point mentioned by Badia was that many artists do not allow their artwork to be exposed to sunlight. In order to apply video, electricity and air conditioner installations Badia created wood panels paralleled to the existing walls and a new gallery floor.

The last restoration was made by the Catalan architect, Jordi Badia, in 2008. I personally interviewed him at his studio BAAS. He told me that the museum restoration was made by a warehouse concept, where initially the artwork exposition was not the main purpose. The natural light use was limited by original structures and the museum direction did not allowed roof openings among other restrictions to prevent artwork damage. It was allowed natural light mainly in the transit areas. Other point mentioned by Badia was that many artists do not allow their artwork to be exposed to sunlight. In order to apply video, electricity and air conditioner installations, Badia created wood panels paralleled to the existing walls and a new gallery floor.

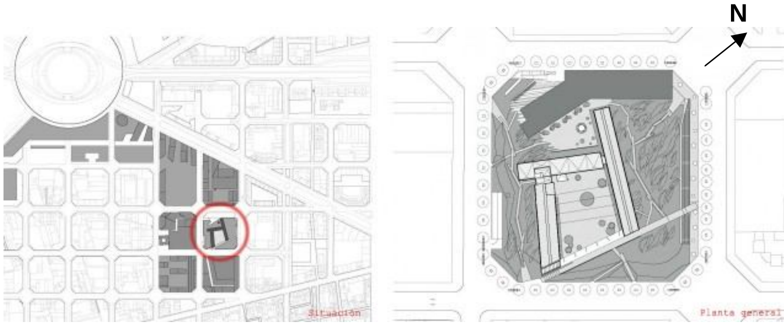


Fig. 47. Can Framis site, Barcelona - Spain
source:http://www.grcstudio.es/portfolio/p-l-o-t-10_museo-can-framis-fundacio-vila-casas/ [accessed in 05/05/2019]

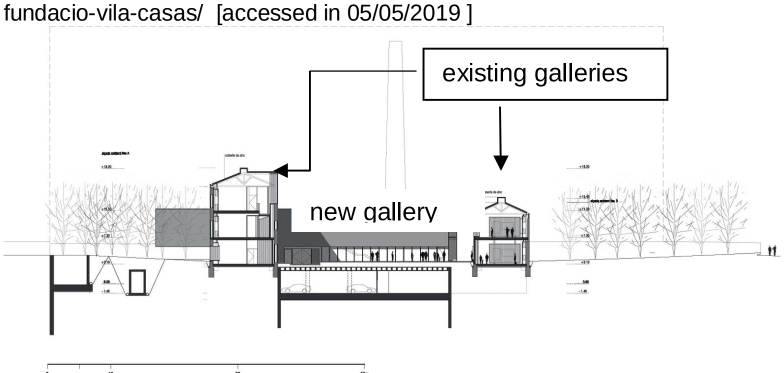


Fig. 48. Can Framis section
source: https://www.archdaily.com/40219/cam-framis-museum-jordi-badia/5011e50f28ba0d5f4c000277-cam-framis-museum-jordi-badia- [accessed 02/05/2019]

The two transversal blocks of the section represents the existing building remained from the textile factory. The longitudinal block in the middle is the new block designed by Jordi Badia connecting the original ones and also locate the museum reception

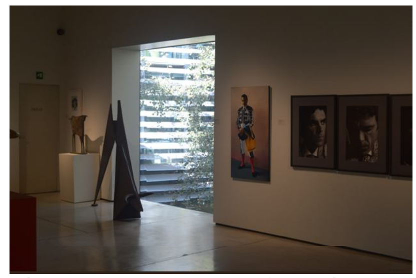


Fig. 49. Upper gallery from the new block.
source: by the author

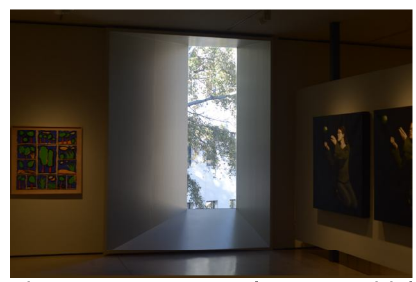


Fig. 50 - Lateral trapezoidal daylight. Due to the thickness and shape this elements diffuses daylight. Upper gallery

source: By the author

The actual project of Can Framis Museum uses natural lighting captured by trapezoidal and narrow vertical openings on the walls bringing a portion of day light into the galleries not totally avoiding direct sunlight in the artwork. In the transit area like corridors and stairs huge window glass are located. The vegetation around outside facades works as a natural barrier. But in general natural light is not uniformly distributed in the space and the central galleries are dark which requires massive artificial light. There is not an automated system to compensate changes in the weather. The level of light on artwork is measured each time a collection changes to keep lux level between 150 and 250 lux in the middle of a painting.

Fig. 53 Existing gallery. Second floor. The layout was inspired in a warehouse. The light source in the end of corridor comes from a skylight over the stairs.

source: By the author

Fig. 51 - Vertical daylight. New gallery, first floor
source: By the author

Fig. 52 Glass curtain. New gallery, first floor
source: By the author

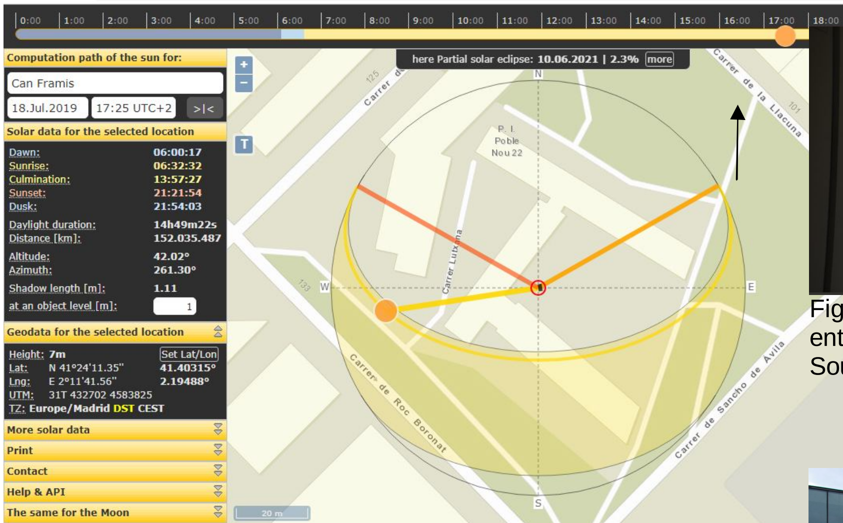


Fig. 54 Sun path projection in the summer, july 18th 2019.The yellow part of the graphic shows that the blocks of the building receive more daylight in the northeast/mornings and southwest/afternoos facades). The orange lines means the solar rays direction at sunrise and sunset. The orange circle represents the sun position (azimute) at 17:25 hours.

source:https://www.suncalc.org [accessed 21/05/2019]

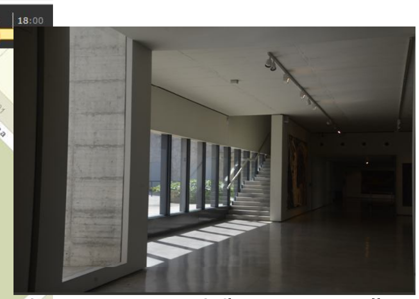


Fig. 56 - Ground floor, new gallery entrance interior
Source: By the author

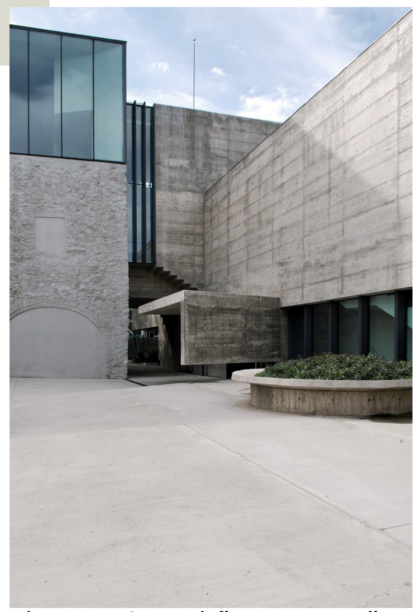


Fig. 57 - Ground floor, new gallery entrance outside
Source: By the author

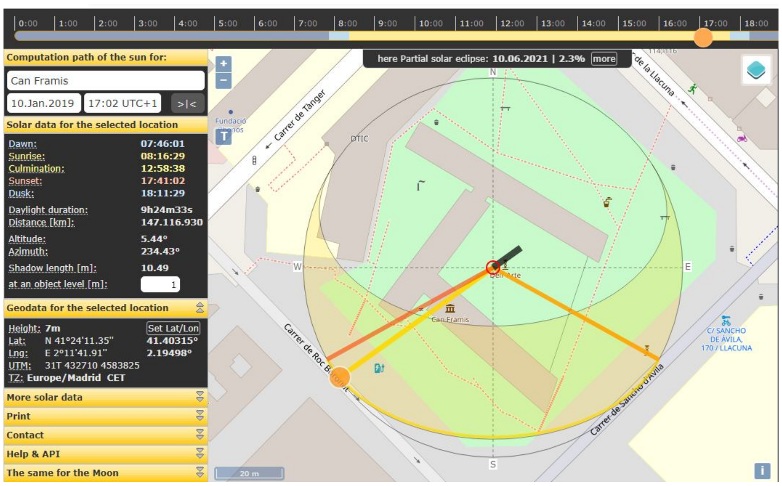


Fig. 55 - Sun path projection in the winter, January 10th 2019.The yellow part of the graphic shows the blocks receive more daylight in the northeast/mornings and southwest/afternoons facades). But in the winter the solar rays direction are almost parallel to northeast facade in the mornings which results in indirect sunlight to this side of the building.

source:https://www.suncalc.org [accessed 21/05/2019]

Fig. 58 - Aerial view and vegetation at northeast and southwest facades.
Source:
https://earth.google.com/web
[accessed 20/05/2019]

4. CAN FRAMIS DATA COLLECTION AND DIAGNOSTICS

4.1 SUMMARY OF RESEARCH METHODS AND DATA COLLECTION

The clipping of the data collection and research in the Can Framis Museum is the upper gallery (second flor) of block A as described at fig.60. At this upper floor there are seven small galleries divided by wood panels as shown in the layout (see fig. 59)

Fig. 59 - Selected galleries 30,33 e 36 (yellow) from the upper floor (block A). The red lines indicates the selected paintings position for light measurements

source: by the author

It was selected three galleries, two at extremes and one in the middle. From each selected gallery was defined four paintings to realize light metering according to fig. 59. At the paintings was taken three points (see fig 62) to read lux level with a luximeter in order to check artificial light and other parameters interferences in this zones.

Fig. 60 - Block division. Block "A" was the selected area to be studied. Source: Google Maps

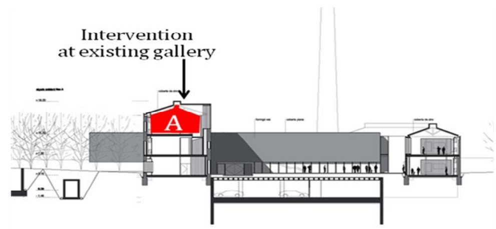


Fig. 61 - Block division. Block "A" was the selected area to be studied. Source: Google images

Fig. 62 - Light measure zones. A luximeter measures the illuminance level that indicates how much light is incident on a surface.

source: by the author

The measurements were done in a clear and a cloudy day at morning and afternoon. One part of the measures were processed with only daylight reaching artwork (it was asked to the museum direction to turn off electric lights) and other part with the combination of artificial and natural light. That way made it possible to analyze daylight qualitatively and quantitatively the incident light in the three zones of each painting. A table with the data collected is presented at table 1 and 2.

DATE	TIME	SKY	AZIM.	ELEV	GALERY	ART	TYPE	SIZE (cm)	N. lam.	LUX DAYL X ARTIF.				LUX DAYLIGHT			
										Z 1	Z2	Z3	gen.	Z 1	Z2	Z3	gen.
23/04	11:30	CLOUDY	116.21	44.91	36	1	mixt technic on canvas	200x150	1	958	740	581	1380	4500	3700	2100	430
						3	Acrylic on canvas	305 x 549	3	1600	1350	1349		1000	1220	960	
						5	Oil on canvas	100 x 100	.1/2	1440	1770	1270		400	120	520	
						7	Mixt on canvas	130 x 163	1	440	500	390		140	120	100	
23/04	11:50	CLOUDY	121.38	48.26	33	25	Acrylic and tint	130 x 194	1	425	285	111	35	0	0	0	0
						27	Mixt on canvas	175 x 200	1	176	150	120		0	0	0	
						28	Oil on canvas i pigm.	198 x 600	.1	490	202	111		0	0	0	
						29	Mixt on canvas	130 x 163	1	348	320	200		30	20	10	
23/04	12:30	CLOUDY	133.99	54.47	30	a	mixt technic on canvas	50 x 50 (x25)	2	518	340	152	440	170	170	180	60
						c	Oil on canvas	100 x 100(4x)	1	138	180	187		70	60	50	
						d	Book page pieces	50 x 70 (2x)	.1	220	235	257		50	40	30	
						f	Mixt on paper	22,5 x 30,5 (x4)	1	723	980	901		190	190	280	
26/04	16:30	CLEAR	243.03	45.83	36	1	mixt technic on canvas	200x150	1	853	710	507	890	290	266	145	530
						3	Acrylic on canvas	305 x 549	3	1652	1440	1020		1400	1060	693	
						5	Oil on canvas	100 x 100	.1/2	1160	1200	970		390	415	474	
						7	Mixt on canvas	130 x 163	1	480	545	456		191	161	145	
26/04	16:45	CLEAR	243.03	45.83	33	25	Acrylic and tint	130 x 194	1	402	293	118	320	0	0	0	0
						27	Mixt on canvas	175 x 200	1	172	147	116		0	0	0	
						28	Oil on canvas i pigm.	198 x 600	.1	464	208	97		0	0	0	
						29	Mixt on canvas	130 x 163	1	343	300	271		30	20	10	
26/04	17:00	CLEAR	250.58	40.32	30	a	mixt technic on canvas	50 x 50 (x25)	2	588	432	236	354	21	21	23	120
						c	Oil on canvas	100 x 100(4x)	1	185	210	208		9	8	8	
						d	Book page pieces	50 x 70 (2x)	.1	254	247	283		9	8	6	
						f	Mixt on paper	22,5 x 30,5 (x4)	1	842	1062	1030		36	41	78	

Table 01
source: by the author

24/05	17:30	CLOUDY	263.33	39.85	36	1	mixt technic on canvas	200x150	1	656	450	330	1030	108	96	45	201
						3	Acrylic on canvas	305 x 549	3	1500	1102	725		700	635	302	
						5	Oil on canvas	100 x 100	.1/2	877	940	776		140	184	263	
						7	Mixt on canvas	130 x 163	1	355	397	380		12	10	8	
24/05	17:40	CLOUDY	263.33	39.85	33	25	Acrylic and tint	130 x 194	1	386	255	152	39	0	0	0	0
						27	Mixt on canvas	175 x 200	1	170	157	118		0	0	0	
						28	Oil on canvas i pigm.	198 x 600	.1	480	210	97		0	0	0	
						29	Mixt on canvas	130 x 163	1	343	330	304		0	0	0	
24/05	17:50	CLOUDY	267,8	35,18	30	a	mixt technic on canvas	50 x 50 (x25)	2	498	277	189	475	1	1	1	1
						c	Oil on canvas	100 x 100(4x)	1	142	180	160		0	0	0	
						d	Book page pieces	50 x 70 (2x)	.1	206	230	240		0	0	0	
						f	Mixt on paper	22,5 x 30,5 (x4)	1	666	886	840		2	2	2	
28/05	10:00	clear/cloudy	94,65	38.81	36	1	mixt technic on canvas	200x150	1	1009	870	840	2400	1158	990	950	177
						3	Acrylic on canvas	305 x 549	3		1990	1860		170	188	250	
						5	Oil on canvas	100 x 100	.1/2	160	165	213		118	115	145	
						7	Mixt on canvas	130 x 163	1	860	720	620		62	62	53	
28/05	10:10	clear/cloudy	94,65	38.81	33	25	Acrylic and tint	130 x 194	1	400	270	145	38	3	2	2	4
						27	Mixt on canvas	175 x 200	1	168	156	130		3	2	1	
						28	Oil on canvas i pigm.	198 x 600	.1	410	246	105		6	4	2	
						29	Mixt on canvas	130 x 163	1	348	392	302		8	8	8	
28/05	10:30	clear/cloudy	99,67	43,84	30	a	mixt technic on canvas	50 x 50 (x25)	2	530	397	195	630	22	22	24	12
						c	Oil on canvas	100 x 100(4x)	1	169	187	237		9	7	7	
						d	Book page pieces	50 x 70 (2x)	.1	254	259	213		8	6	4	
						f	Mixt on paper	22,5 x 30,5 (x4)	1	760	1002	952		30	27	32	

Table 02
source: by the author

4.1.2 ZONE LIGHTING ANALISYS

ARTIFICIAL LIGHT + DAYLIGHT

For this mixed light, the **Zone 1** presents more intense light due to the focus of the electric lamps. Zone 2 and 3 decreases illuminance values respectively. In case of some incidence of side daylight and reflections from the white floor, zone 3 can present higher values than zone 2.

DAYLIGHT ONLY

For natural lighting, the Zones intensity in terms of lux detected by the luximeter varies more between the zones. There is a predominance of zone 1 as the most intense because the sunlight comes from above, naturally the higher positions receives more light fallowed by the zone 3 with higher lux level probably due to floor reflections.

4.1.3 GALLERIES LIGHTING ANALISYS

GALLERY 36

This gallery is located closed to the connection of block A and B and receives a lot of daylight directly from the big transparent glass curtain that opens to the central external area of the museum (fig 63). This gallery has the higher lux level among all galleries extrapolating the required level according to regulations. According to tables 01 and 02, at zone 02 for instance (artificial + daylight), the majority of the lux level exceeds the recommended value between 150 and 200 lux for paintings. Although it's a museum's concern and procedure to make lighting measures, in the galleries that concentrate more daylight there is not a control element such diffuser, blinder, etc and the general natural light in the middle galleries are not present resulting in much more darkness and use of artificial light.(fig 65 and 66)

The artificial light focus reaches also the wall around the framework (fig 63)what is not appropriate. The electric light should illuminate only the painting area. this gallery presents one of the biggest paintings from the museum, 305x 549 centimeters.

Fig.63. Gallery 36. Second floor of existing block A. Artificial light + daylight.
source: By the author

Fig.64. Gallery 36. Second floor of existing block A. Daylight only. Natural light is sufficient to illuminate this gallery. Just some artificial light at specific artwork would be required.

source: By the author

GALLERY 33

This gallery (fig.65) is located in the middle of the second floor area and presents the daylight blocked by internal wall panels that separates the seven existing galleries resulting in the darkest space. The lux level is ''0"" for only daylight and electric light is used to keep visibility. The lux level is extrapolated in some zones.
When the artificial lights were turned off, it is possible to see how little natural light illuminates the space (fig. 66)

Fig. 65 - Gallery 33. Artificial light + daylight.
source: By the author

Fig 66 - Gallery 33.
daylight only
Source: by the author

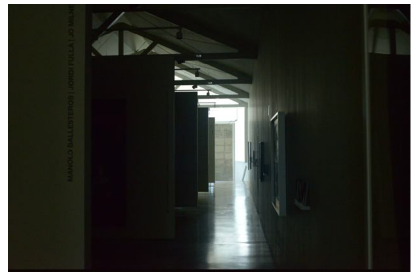


Fig 69 - Corridor upper floor, block A. Daylight only. This picture shows how natural light is poorly distributed and blocked by the wall panels that separate galleries
Source: by the author

GALLERY 30

This gallery (fig. 65) is located in the other extreme of the floor and receives daylight from two sides. One from the stair skylight and other small trapezoidal side window. A makeable characteristic of this gallery is the indirect sunlight that increases the lux level of zone 3 probably also reflected from the white concrete floor. Only daylight do not achieve the minimum lux level required.

Fig 70 - Corridor upper floor, block A. Daylight + artificial light
Source: by the author

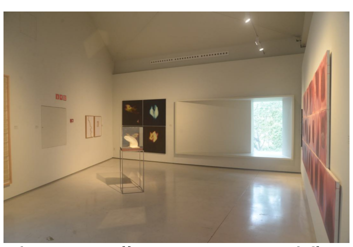


Fig.67. Gallery 30. Second floor of existing block A. Artificial light + daylight
source: By the author

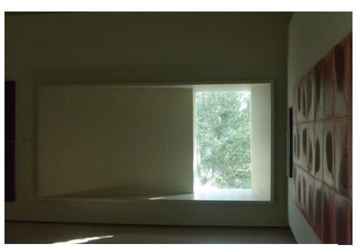


Fig 68 - Gallery 30.
Daylight only
Source: by the author

4.2 DIAGNOSTICS

The original structure of the building's wall related to the second floor of block A are made by bricks with a series of windows (1,10 x 1,80 meters) located longitudinally. The restoration made by Jordi Badia kept these light openings closed to avoid daylight inside and created new glazes at transit areas. The trapezoidal opening at gallery 30 (fig 67) actually is a fire security entrance. Generally there is no daylight distributed homogenously to all galleries of that floor and no skylight directly on the galleries. The daylight map of the actual floor is shown at figure 72.

Fig.71. Gallery 30. Second floor of existing block A. Natural light comes from the skylight over the stairs.
source: By the author

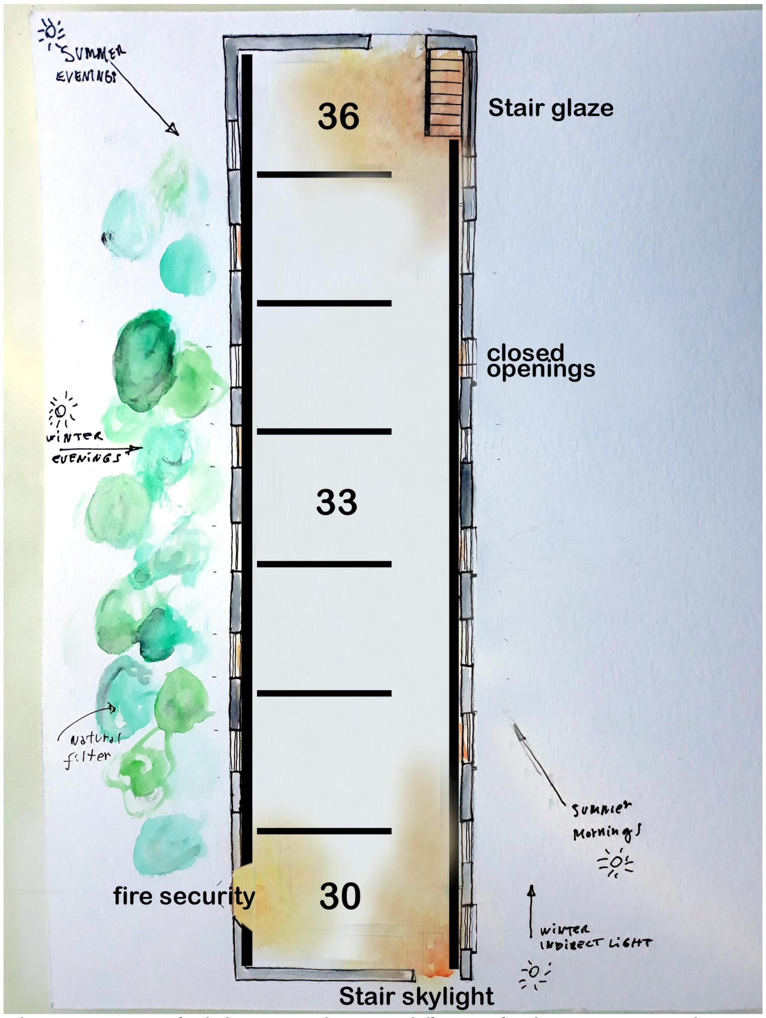


Fig. 72 - Natural Light map of second floor, Block A, Can Framis Museum, Barcelona - Spain. The orange tones represents natural lighting entrance by the described openings.

Source: by the author

Fig.72 - Gallery 30. Second floor of existing block A. Natural light comes from the Fire security trapezoidal window
source: By the author

Fig.73 - Gallery 30. Second floor of existing block A. Natural light comes from the stair glazing
source: By the author

Daylight is heterogeneously distributed on the floor illuminating only the gallery 30 and 36 which are extreme galleries closed to stair ways. Natural lighting enter these galleries only by lateral openings what means that the lightest areas are the ones closed to this openings, confirmed by measures at tables 01 and 02. No sunlight comes from skylight. The central galleries receives little daylight because there is no openings to exterior and also because the layout (parallel wood panels) blocks the sunlight that enter from the extremities. An change in the layout could allow more daylight at central areas and of course make light penetrates from the existing wall openings. To avoid direct daylight, blinders and diffusing surfaces could be used and sensors to compensate lack of daylight.

Qualitative photo analysis demonstrates that the white and polished floor reflects too much light resulting in undesired glare. Artificial light focus spread light out of the paintings washing the wall around. this situation could be resolved with a lamp focus adjustment or other kind of lamps.

The measures presented on tables 01 and 02 demonstrate that the required lux level for paintings according to regulations are not satisfactory when artificial light is applied, it exceeds 200 lux. Only daylight could be reasonable for gallery 36, but the other galleries are less than 150 lux. To keep the required lux level it is needed artificial light potency adjustment combined to daylight treatment.

BLOCK "A" DAYLIGHT ORIENTATION

The block A receives more top daylight during the summer. It would be useful to use skylight in this area with adequate sunlight diffusion and control. During summer and winter southwest facade receives more direct daylight which could be an opportunity to illuminate inside the exhibition space through its side where artwork less sensitive to light should be located. Nowadays this facade has a lot of trees that filter daylight. But in a general situation, control elements should have a high percentage of blocking light.

In the northeast facade of block "A" during summertime it receives direct daylight in the mornings. In the winter this facade perceives indirect daylight the whole day because for instance, In January 10th at 10:00 o'clock, the sun azimuth is about 138^0 , not reaching the facade with direct angle. In this position the opportunities to locate artwork in a museum would be more advised to use more light sensitive art pieces. In terms of control elements it is recommended to diffuse daylight partially or softly.

5.DAYLIGHTING UNIT MODEL

5.1 SUMMARY OF PHOTOGRAPHIC METHODS AND DATA COLLECTION INTO THE DAYLIGHT UNIT MODEL

Since the beginning the idea was to register natural light into a box to observe and analyze its characteristics and changes at different weather conditions. The box scale would present real light performance as a building on it's size promoting analyses from a more realistic approach that 3D digital modeling could not do. The light unit model has 3 movable side panels and the top has a opened square that allows skylight form changes like shed, shelves, flat, rounded. The movable sides gives the possibility to test different materials simulating window light control like glazing, curtains, blinders, window screen.

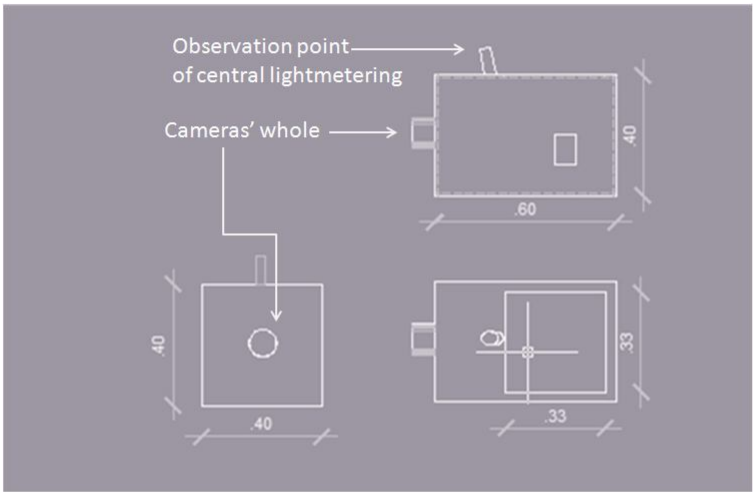


Fig 74 - Unit light model plans with dimensions. Upper side is a lateral view, right bottom is a superior view, bottom left is a frontal view. The dimensions described are in centimeters
Source: by the author

Fig 75 - Daylight unit model - top and side openings to experiment light control materials

Source: by the author

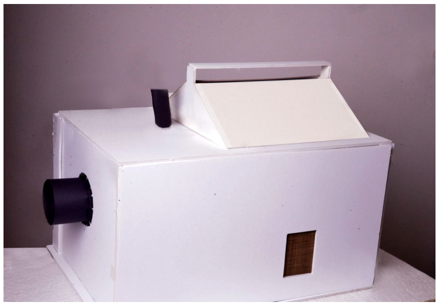


Fig 76 - Daylight unit model - top with shed (chimney effect) and side opening with brown window screen 1%

Source: by the author

The scale of the box was 1:20. The measures of the box correspond to a real space about 12 x 8 x 6 meters. The high of 6 meters is proposed for a museum by Neufert in his book, *Architect's data* (pag 611).

The material of the box was made by white foamboard for its facility to create cuts and because normally an art gallery is painted in white. But to ensure that no unwanted light get inside from its porous, a black cloth was used outside. What is recommended is that a non-porous and maleable material is ideal in order to let just the light from the openings get into the box.

5.1 DATA COLLECTION

The box was used to collect qualitative data (images) with the camera through the camera's whole. A luximeter collected the quantitative data at two points, a central point at the box's base and a central point at the box's frontal side (normal location for a painting).

The images can register light characteristics as direction, color temperature, intensity, contrast. The lux levels can reveal the illuminance level on the surface demonstrating the variation proportion between different materials.

Fig 78 - Daylight unit model - luximeter at central box's base

Source: by the author

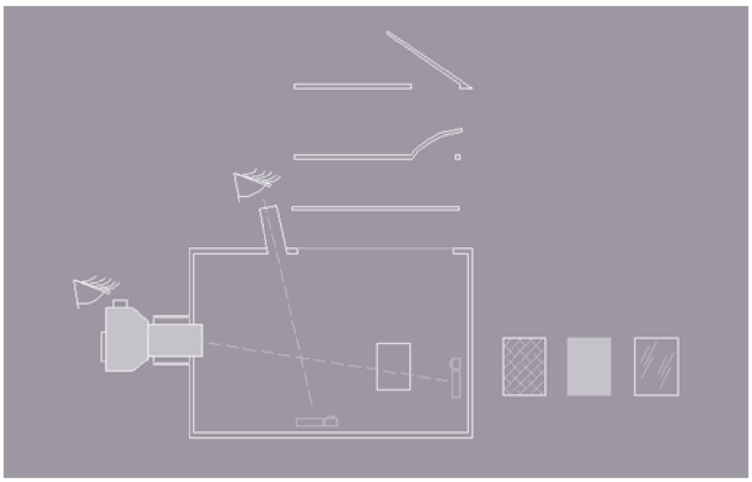


Fig.77 - Daylight Unit Model workflow. The image shows the two lux measure points and the camera position. Also suggests the light control elements change.

Source: by the author

Fig 79 - Daylight unit model - skylight Shed.

Source: by the author

5.1.2 CAMERA ADJUSTMENTS

The camera used was a Nikon D600. The manual configuration was the same for all photos in order to keep the same pattern for qualitative analysis. The main camera variables is shown below:

APERTURE f10
SHUTTER.................................... 1/60
ISO.. 100
W/B... CLOUD
LENS... 24 mm

5.1.3 EXPERIMENT PROCEDURE

The experiment was made during clear and cloudy days because under this conditions daylight is more stable. Was chosen light control elements one by one separated to guarantee the properties results independently. The procedure steps are as follows:

1 - Selection the weather condition
2 - Selection of the time
3 - Placement of the light unit model box at an open area
4 - Positioned the box orientation (opposite side of camera whole) to North
5 - Selection of the light element control (skylight, side window, window treatment)
6 -Selection of the light element control orientation (varies orientation can be done to study)
7 - Installation of the light element (skylight or sidelight) control and block any other light entrance
8 - Location of a luximeter at central box's base point
9 - Reading and noting the lux level on a table
10 - Location of a luximeter at central box's wall point
11 - Reading through camera's whole and noting the lux level on a table
12 - Removal of the luximeter
13 - Observations of the light visual characteristics through the camera's whole. Attention to the light at the floor and the three walls. Note takings to a table.
14 - Placement of the camera lens at the camera's whole
15 - Picture taking with the camera adjustments suggested on item 5.2

The measures made in this experiment is presented on table 03 and pictures are shown on a catalogue sample in chapter 6.

DATE	TIME	SKY	ORIENT.	TYPOLOGY	MATERIAL CONTROL	SIZE (cm)	LUX	
							center	wall
17/07	15:30	clear/clou	**west**	SIDE WINDOW	Curtain PEARL 1%	7X10	600	770
17/07	15:30	clear/clou	**west**	SIDE WINDOW	Curtain BROWN 1%	7X10	350	440
17/07	15:30	clear/clou	**west**	SIDE WINDOW	translucid glass	7x10	3400	2880
17/07	15:30	clear/clou	**west**	SIDE WINDOW	transp. Glass	7X10	3200	3970
20/07	11:00	cloud	**east**	SIDE HOR. AL=1m	transp. Glass	30X10	170	250
20/07	11:05	cloud	**east**	SIDE HOR. AL=2m	transp. Glass	30X10	510	490
20/07	11:10	cloud	**east**	SIDE HOR. AL=3m	transp. Glass	30X10	1130	740
20/07	11:20	cloud	**east**	SIDE VER. AL=1m	transp. Glass	10X10	30	40
20/07	11:25	cloud	**east**	SIDE VER. AL=2m	transp. Glass	10X20	70	70
20/07	11:30	cloud	**east**	SIDE VER. AL=3m	transp. Glass	10X30	90	100
20/07	16:00	cloud	**east**	SIDE HOR. AL=1m	Curtain PEARL 1%	30X10	60	70
20/07	16:15	cloud	**east**	SIDE HOR. AL=1m	translucid paper	30x10	240	180
24/07	16:00	clear	**west**	SIDE VER. AL=3m	transp. Glass	10X30	5500	4800
17/07	16:00	cloud	**north**	FLAT SKYLIGHT	vegetal paper	33X33	1900	2700
17/07	15:30	clear	**west**	TRIAN. SKY shed 30	open one side	33x9	2140	2630
17/07	15:40	cloud	**south**	TRIAN. SKY shed 30	open one side	33x9	200	190
17/07	16:20	clear	**south**	SKY REFLECTOR shelve	open one side	33x10	340	360
17/07	16:15	cloud	**west**	ROUND. SKY SHED	open one side	33x9	1980	1560
16/07	16:20	cloud	**south**	ROUND. SKY SHED	open one side	33x9	140	130
16/07	16:30	clear	**N/S**	Lanternin	open left side	33x3	2120	2190
16/07	16:35	clear	**N/S**	Lanternin	open right side	33x3	600	610
16/07	16:40	clear	**N/S**	Lanternin	open two side	33x3	1880	1710
24/07	16:15	clear	**E-W**	Lanternin	open two side	33x3	1300	1380

Table 03

5.2 ANALYSIS OF LIGHTING REGISTERS

The analysis of the experiment is done qualitatively by observations and photography, quantitatively by lux table. This research does not have the proposal to come out with a hermetically closed conclusion, solution or definition into natural lighting characteristics and properties applied to art space or any other. This analysis indicates possibilities that a light designer can take into consideration when projecting by consulting a catalogue or creating their own experiment. The registers and measurements can bring some verifications related to daylight reflections, intensity, diffusion, iluminance, better orientation to skylight and sidelight elements, etc

Fig. 82 - Light Copula (Chimney effect). North-South position , best orientation to capture diffused light

Source: By the author

5.2.1 LIGHT CONTROL ELEMENT ORIENTATION

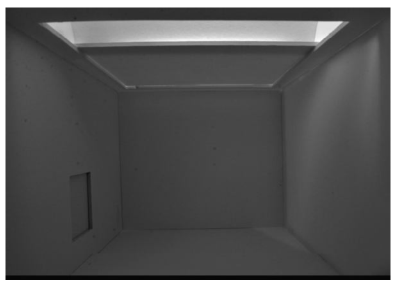


Fig. 80 - Light Shed - North
Source by the author

Fig. 81 - Light Shed - South

The images in figure 80 and 81 were taken in July 17th, at 16:30 h (Salvador, Bahia - Brazil), south hemisphere, clear sky. In figure 80 the shed orientation was opened to North. As the sun was positioned west at 16:30h, sunrays reached the right side of the box painting a sharp white area which is not a desired light condition for an art exhibition space causing damages to an artwork. The orientation to South presented in figure 81 brings a diffused light into the space. As in the south hemisphere, the sun path goes from east to west through the north, the south will receive more indirect daylight captured by the shed with this orientation. The experiment shows its importance as an instrument for natural light study.

Fig. 83 - Light Copula (Chimney effect). East-West orientation receives more direct daylight during the day capturing light from the whole sunpath causing flare.

Source: By the author

5.2.2 LIGHT CONTROL ELEMENT DIFFUSION

In term of quality of light, daylight is unique. Its color range is superb, however the potential damage direct sunlight can cause in term of UV radiation and heat has to be taken into account. Daylight can still be used in museums and galleries spaces as long as its controlled and diffused.[23]

Fig. 84 - Open sidelight

Source: By the author

Diffusion is a very important light condition appropriated to artwork exposition. First of all it preserves artwork against possible damages, other point is that the observer can read a painting for instance, without changes in the original colors or distortions.

Figure 84 shows a lateral opening with no window light control element, so the sunlight gets directly inside the space projecting a highlighted area on the floor. Figure 85 presents a translucid window glass that diffuses daylight projecting a soft light inside without delineated lines on the floor. The lux measurements of the experiment demonstrated that translucid glass diminished 57 % of sunlight at a point 20 cm (equivalent to 4 meters) from the window.

Fig.85 - sidelight with translucid glass

Source: By the author

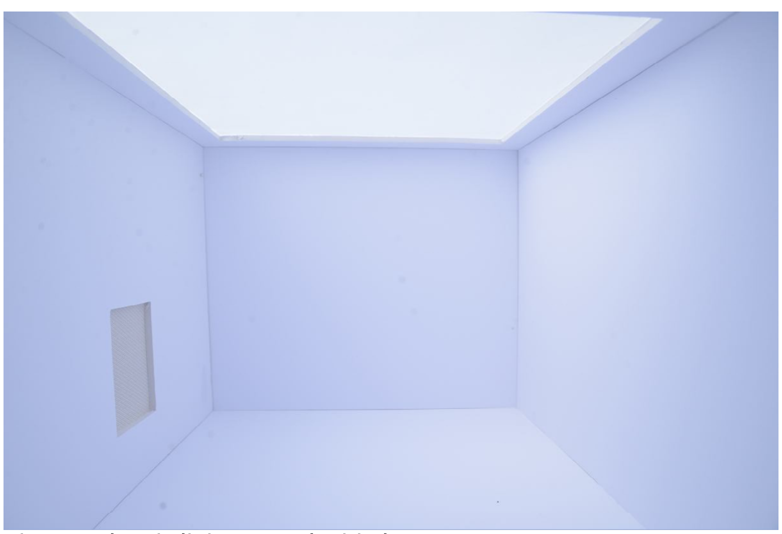


Fig. 86. Flat skylight. Translucid glass
Source: by the author

23 Feilo Sylvania, " Lighting for museums and Galleries," Havells Sylvania copyright 2015

Figure 86 demonstrates a homogeneous light into the space diffused by a skylight with the aperture almost the same side of the roof area, a strategy used by Renzo Piano in some projects with different glass layers and diffuser paper.

Fig. 88 - Horizontal opening (30x5 cm) with single glass. illuminates bottom areas of the space. Illuminance level on the center of the floor = 170 lux
Souce: by the author

5.2.3 LIGHTING FORM

The unit box can also make it possible to explore opening form by scaling change. From this a luximeter was used to measure illuminance level by varying opening dimensions. The result is that its possible to establish a proportion factor between size and lux level at the measure points into the box.

Figures 88, 89 e 90 shows the size change of the opening. In terms of illuminance level, when the high double, the lux level triplicates.

Fig. 89 - Horizontal opening (30x10 cm) with single glass. illuminates bottom areas of the space with more expansion bringing more light to the whole space. Illuminance level on the center of the floor = 510 lux
Souce: by the author

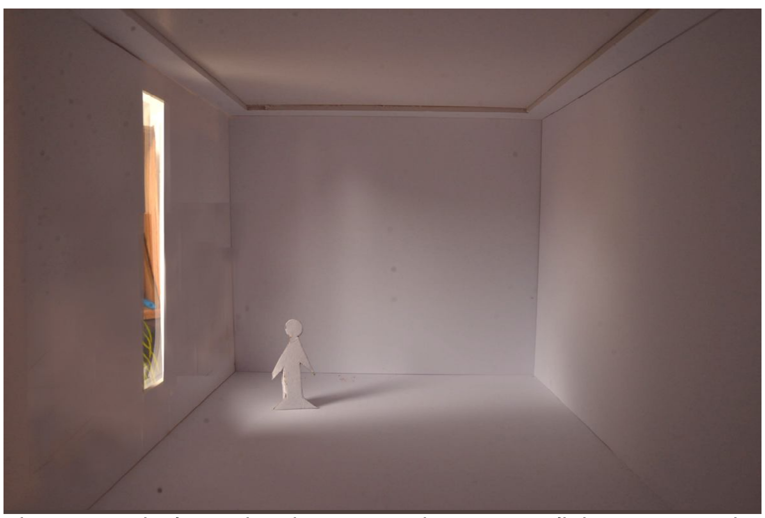


Fig. 87. Vertical opening (10x25 cm). A narrow light range reaches the space on
the foor and upper walls, creating dark zones.
Souce: by the author

Fig. 90 - Horizontal opening (30x15 cm) with single glass expands the general illumination. Illuminance level on the center of the floor = 1300 lux
Souce: by the author

The possibility of studies into the Daylight Unit Model are endless. keeping elements fixed and changing just one variable of the system its possible to very a lot of conclusions. It was very helpful and didactic, for instance, to observe the lighting changing when the light shelf at a side window was moved forward and backward. Scientific studies affirm that daylight functions the same way as much as a scaled model as in the real space with +- 4% error

6. CATALOGUE FOR DAYLIGHTING DESIGN

6.1 CATALOGUE OBJECTIVES

The main purpose of the Catalogue is to present and integrate information about daylighting capturing and control. It's an instrument to help designers to make lighting decisions and predict results based on a real experiment that elucidates qualitative and quantitative data. The catalogue also provides some daylight parameters, characteristics, analysis and guidelines based on a specific site orientation and weather conditions that can be used as a reference.

The intention of this research is not come out with a complete or extended catalogue, but present the main book structure and how the information was integrated. The chapters suggests that similar conditions are put closer in order to provide data comparisons.

Fig. 92 - Triangular traditional Shed
Source: by the author

6.2 CATALOGUE PARAMETERS

The upper area (see figure 91) introduces the typology of the lighting structure (in this case, triangular shed). Bellow there is a sketch that shows the element location and principle of function demonstrating how the sunrays reaches the interior of the space. The yellow hidden lines represent the sun angle at the moment the image was taken in the winter, the red hidden line represents the sun direction in the summer.

Fig. 93 - triangular shed
Source: by the author

The image at bottom right is the image taken into the lighting unit model box. From this image is possible to see which side receives more light and the general illumination of the space.

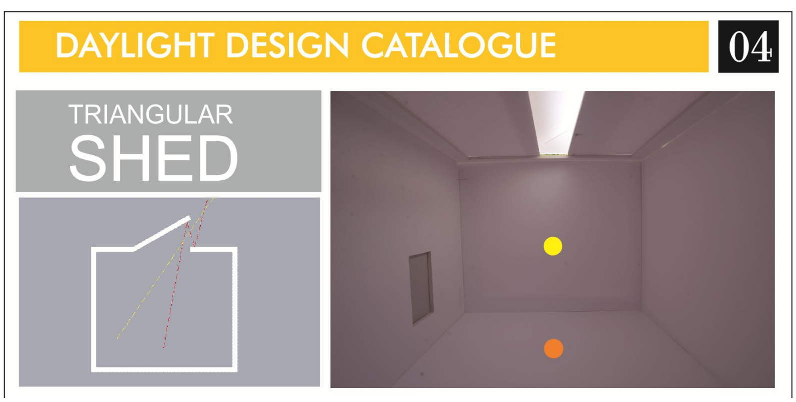
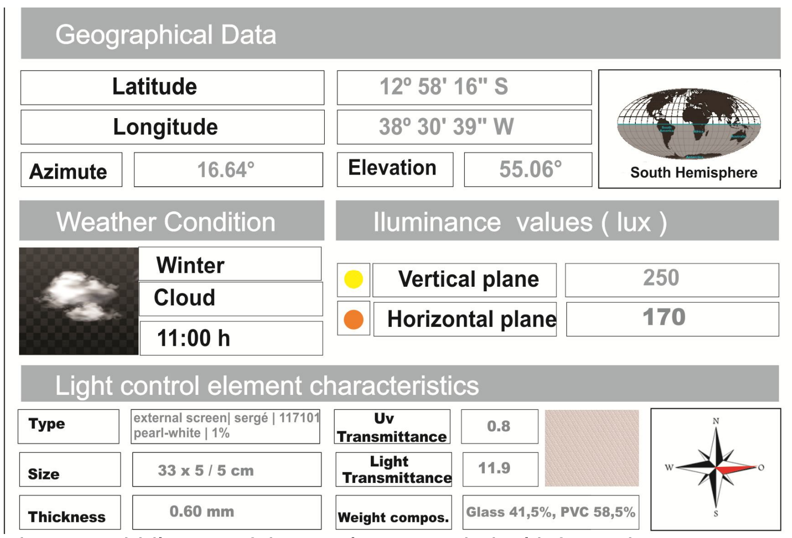


Fig. 91 - Upper area of the technical page of the catalogue. Typology specification and experiment image.
Source: by the author

Fig. 94 - Horizontal sidelight
Source: by the author

The yellow circle represents a measure point in the wall (vertical plane) for the iluminance level (lux) and the orange circle, the floor point (horizontal plane). Comparing, for instance, this data with different materials with the same opening, time and weather condition, it's possible to verify the capability of daylight reduction from one material to another in terms of illuminance.

Figure 95 delineates the middle part of the catalogue which provides technical information as geographical data like weather condition, illuminance values (associated to the points in the upper right image) and the light control element characteristics, orientation during the experiment and a sample of the material texture.



Geographical Data

Latitude	12º 58' 16'' S	South Hemisphere
Longitude	38º 30' 39'' W	
Azimute 16.64°	Elevation 55.06°	

Weather Condition

Winter	
Cloud	
11:00 h	

Iluminance values (lux)

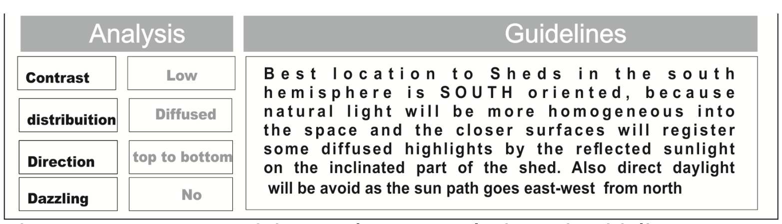
Vertical plane	250
Horizontal plane	170

Light control element characteristics

Type	external screen| sergé | 117101 pearl-white | 1%	Uv Transmittance	0.8
Size	33 x 5 / 5 cm	Light Transmittance	11.9
Thickness	0.60 mm	Weight compos.	Glass 41,5%, PVC 58,5%

Fig. 95 - Middle part of the catalogue. Technical information
author: by the author

The bottom part (figure 96) is dedicated to provide some analysis of daylight quality and a short text for guidelines and considerations about the recommended orientation for the typology in question or any pertinent comment.



Analysis		Guidelines
Contrast	Low	Best location to Sheds in the south hemisphere is SOUTH oriented, because natural light will be more homogeneous into the space and the closer surfaces will register some diffused highlights by the reflected sunlight on the inclinated part of the shed. Also direct daylight will be avoid as the sun path goes east-west from north
distribuition	Diffused	
Direction	top to bottom	
Dazzling	No	

Fig. 96 - Bottom part of the catalogue. Analysis and guidelines
author: by the author

Fig. 97 - Combination of toplight and sidelight. The combination of elements distribute light to dark areas of the space balancing the general luminosity.

Source: by the author

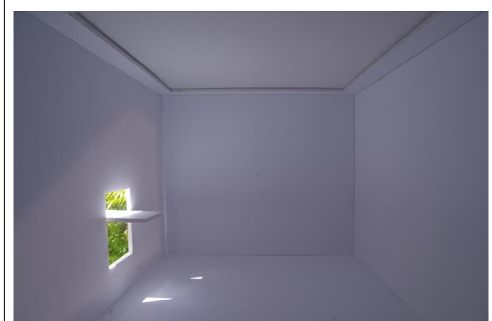


Fig. 98 - Lateral Light shelf. The experiment explicit that the window light shelf diminished the lux level at a point on the floor distant 20 cm (equivalent to 4 meters in real size) from the window in 92 % illuminating the ceiling and bringing general light to the space by reflection.

Source: by the author

6.3 CATALOGUE DESIGN

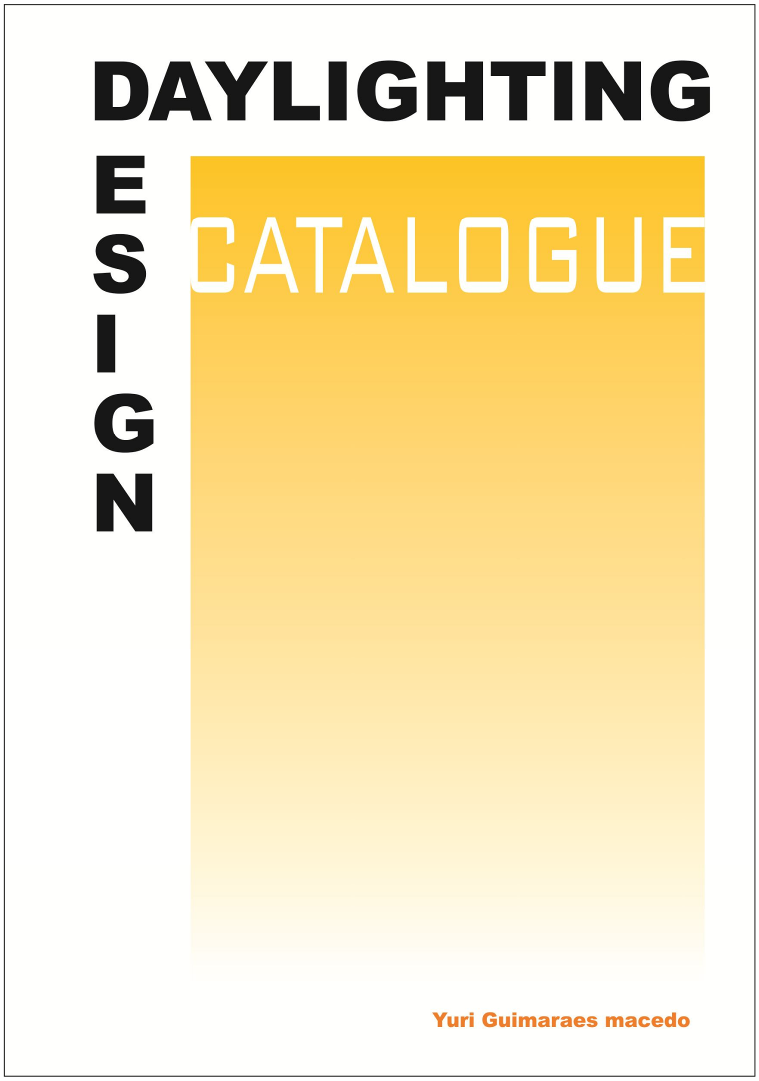


Fig. 99 - Catalogue cover.
Size of production : 15 x 21 cm
Paper: Brilliant Couchet 180 gr

Source: by the author

Fig. 99 - Catalogue back cover.

Source: by the author

contents

Fig. 100 - Catalogue content

Source: by the author

1.Introduction

This catalogue represents the results of a research in natural lighting based on observations, photography and measurements into a Unit Model box. There are two kinds of collected data, one is qualitative derived from ambience and photo observations and other is quantitative represented by iluminance level measures at a vertical point (wall) and a horizontal point (floor).
The box scale is 1:20 representing a space about 12 x 8 meters (base area) and 6 meters high. Studies demonstrate that a scaled model presents the same level of iluminance as the real space (with +-4% error). The main purpose of the catalogue is to organize information about materials, shapes and typology about natural lighting control to be applied to sustainable design; provide realistic content about light diffusion and distribution into the architectural space. The data organization of the catalogue pages are as follow: Geographical data, weather condition, Iluminance values, lighting control element characteristics, analysis and guidelines. Similar aspects are located in pages next to each other to provide visually and/or technical comparisons.

Fig. 100 - Catalogue introduction

Source: by the author

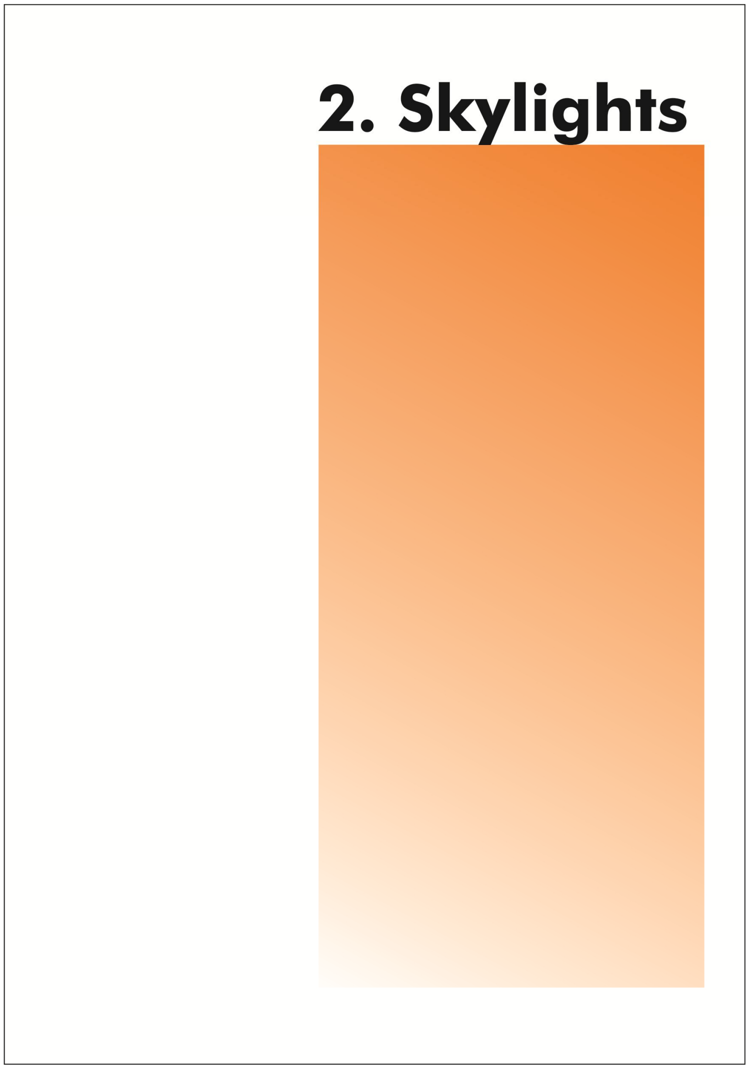


Fig. 101 - Catalogue Chapter presentation topic

Source: by the author

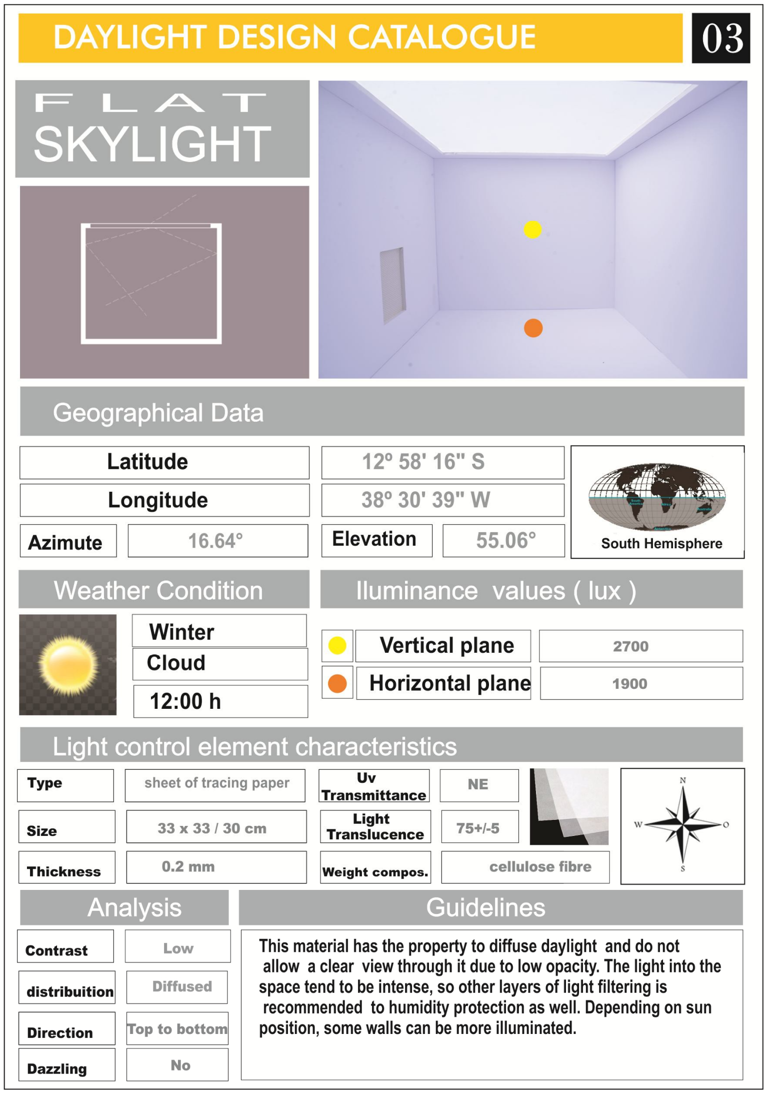


Fig. 102 - Catalogue main technical information page. Flat Skylight with diffuser element

Source: by the author

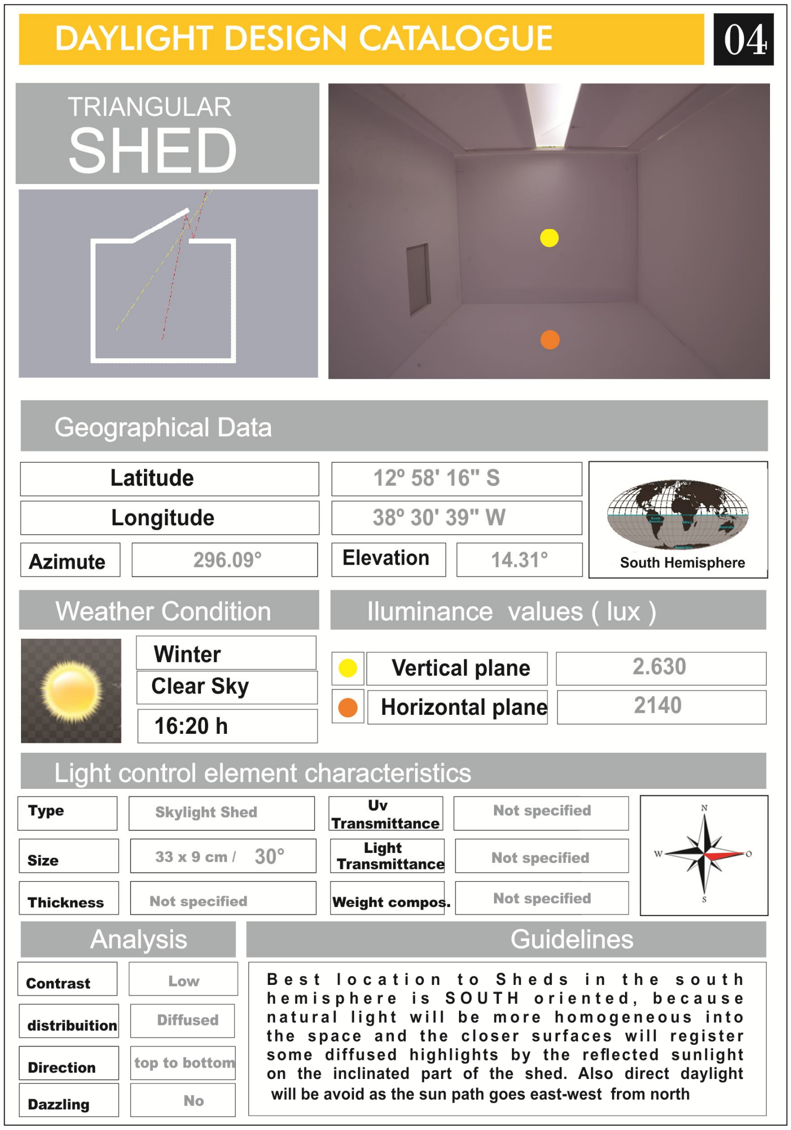


Fig. 103 - Catalogue main technical information page. Triangular Shed Skylight

Source: by the author

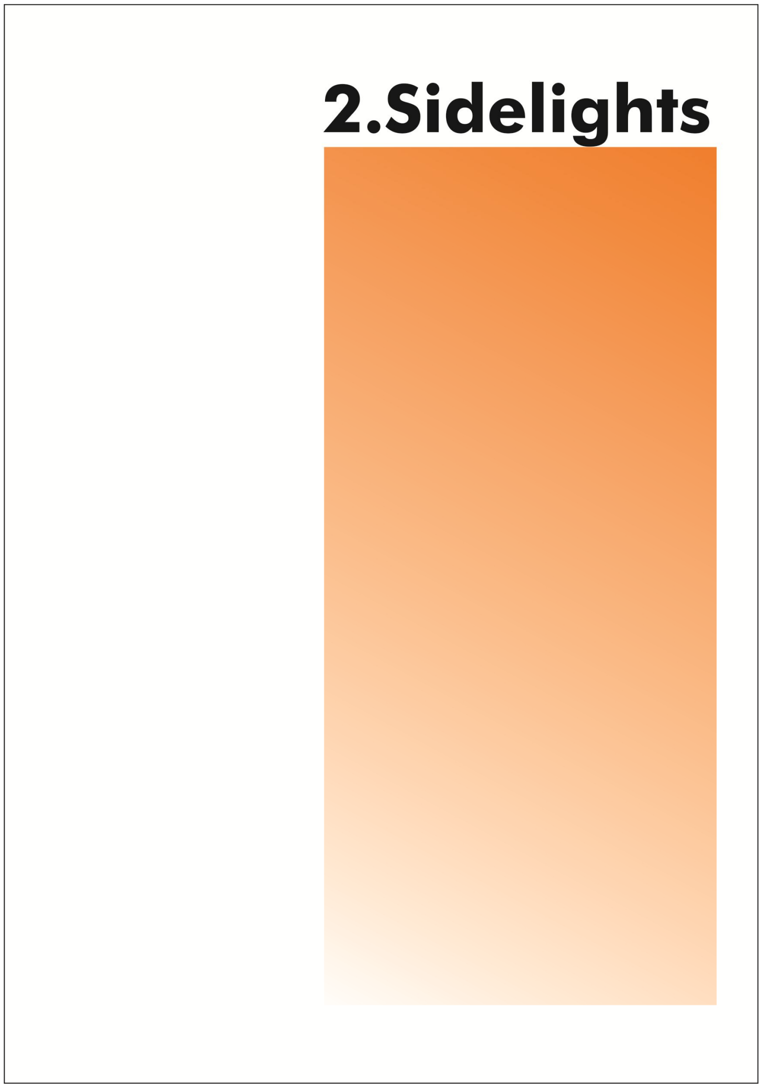


Fig. 104 - Catalogue chapter presentation topic

Source: by the author

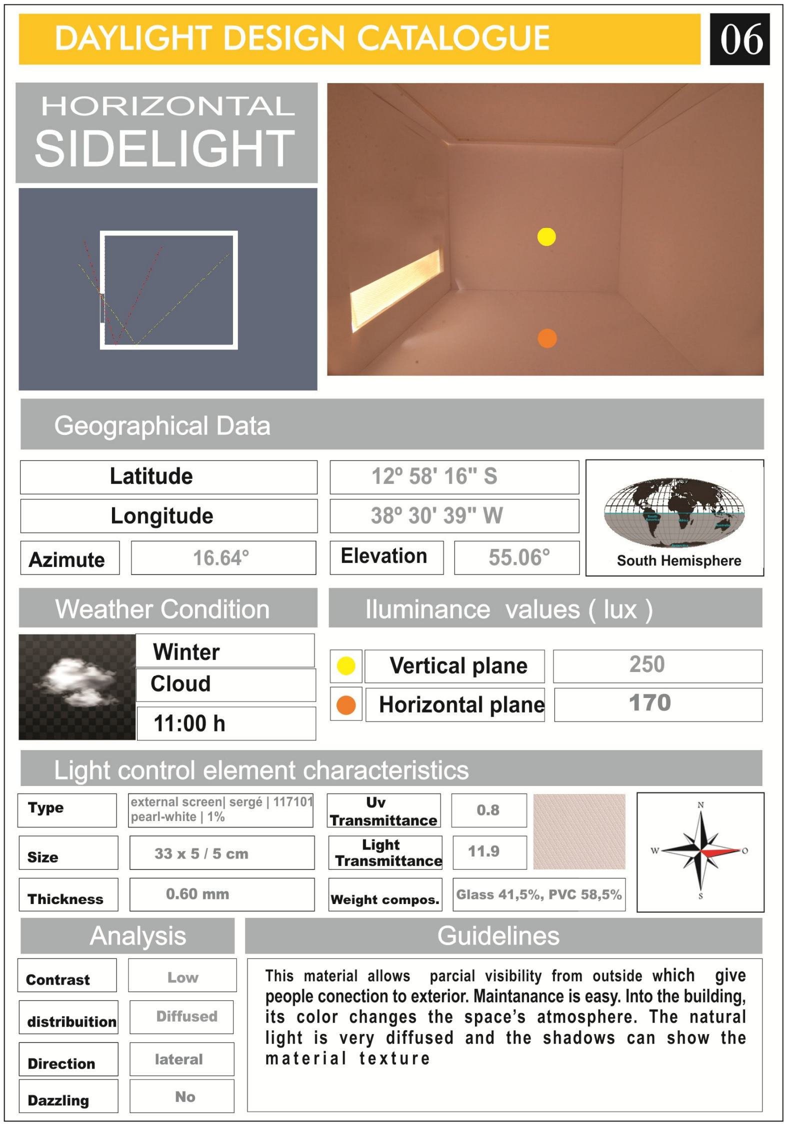


Fig. 105 - Catalogue main technical information page. Horizontal sidelight with external diffuser screen.

Source: by the author

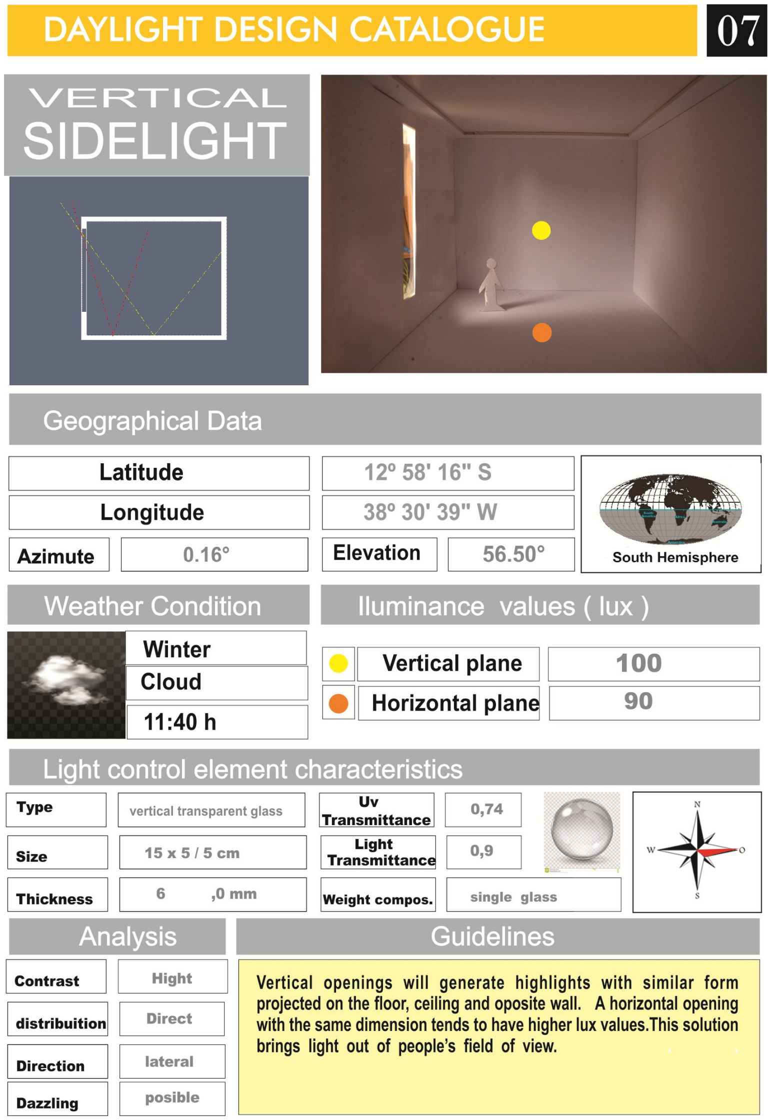


Fig. 106 - Catalogue main technical information page. Vertical sidelight with transparent single glass

Source: by the author

7. CAN FRAMIS

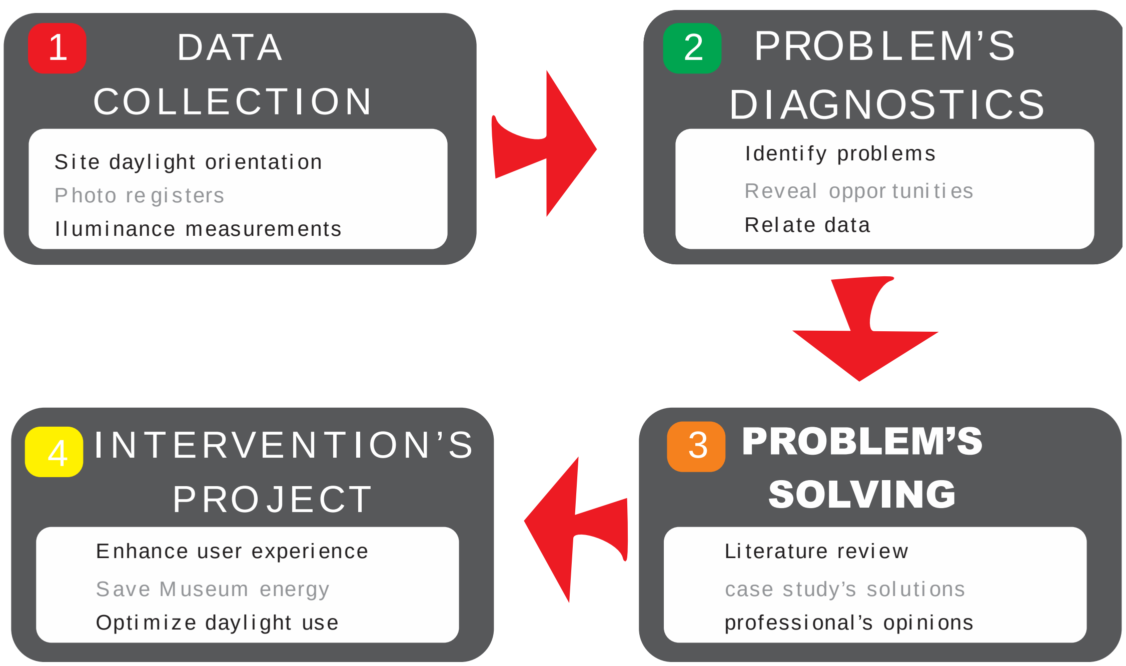
IMPLEMENTATION PROJECT

7.1 INTRODUCTION

The luminous intervention's project objective is to distribute daylight homogenously into the galleries of the existing upper floors. They main idea is to use the original elements like the line of vertical openings and the roof industrial Shed that were all closed to avoid direct sunlight. As opening this elements, to reach uniform natural light inside and protect artwork, light control elements are proposed and an integrated system to artificial light. The studies developed at Block "A" can be used for block "C" as well, once it keeps the same typology and similar problematic

7.2 PROJECT PROCESS

The project process is described in the workflow bellow and the detailed observations from phase 1 to 3 were presented at the previous chapters



7.3 PROJECT PLAN

The main objective of the project was to create elements to control daylight, preserving artwork and provide a satisfying experience to users . The collected data was a important source to diagnose lighting problems. The researches and study cases enlightened solutions to solve the detected problems. The light control elements suggested are listed bellow and illustrated at figures 107 and 108:

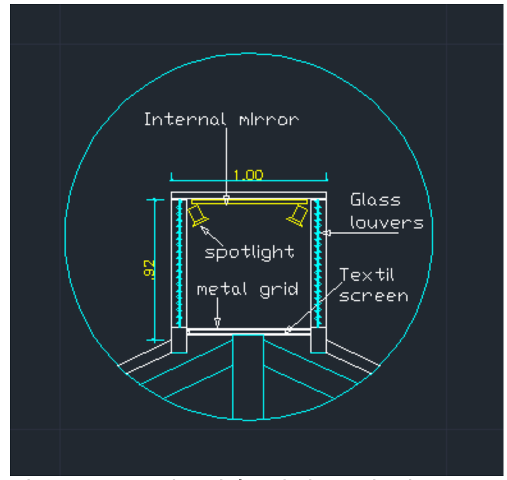


Fig. 107 - Industrial existing Shed with new automated system and elements
Source: By the author

a. Automated Shed with bilateral glass louvers and top internal mirror. The louvers allow hot air to go out of the building and they let daylight comes in directly or indirectly. A sensor will ready the level of luminosity and adjust the blinders movement automatically in order to diffuse natural light when needed. The top mirror emphasize the light reflection that goes down into the gallery.

b. Central triangular clerestories. This intervention on the roof will bring indirect daylight reflected on it's interior surfaces and the white gallery ceiling.

c. External textil blind panel with dark color for sidewindows. The dark color for textils absorb 96% of solar radiation and avoid the heat entrance. The light color would block 79%. By the way, as much as exterior is located the solar protection, more energy is saved.

d. Internal textil screen with light color for sidewindows to enhance interior luminosity and allow outside parcial view.

e. Internal color painted movable panels on trail. This structure is painted in white in one side and colored on the other side. When located close to the opened windows, the sunlight reflects on the colored side bringing into the gallery shades of color. The purpose here is to work with a metaphorical sense of daylight .

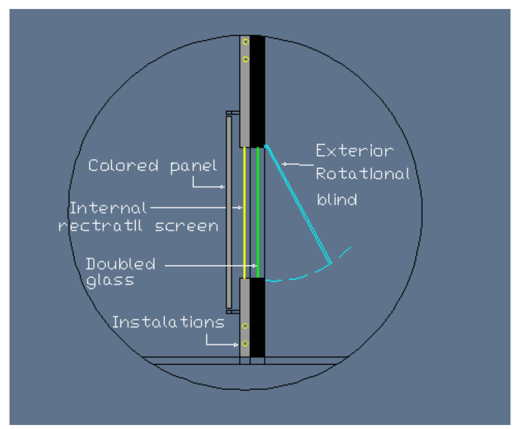


Fig. 108 - facade Can Framis's wall with lighting control elements

Source: By the author

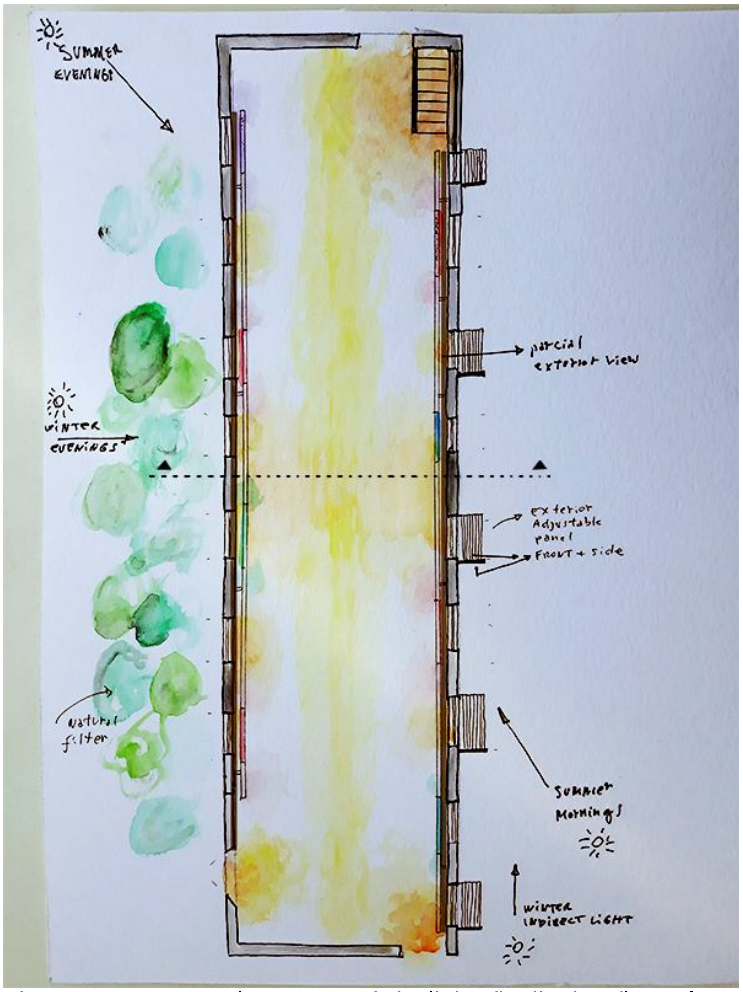


Fig. 109 - Watercolor proposed daylight distribution floor plan and main sunrays direction in summer/winter.
Source: By the author

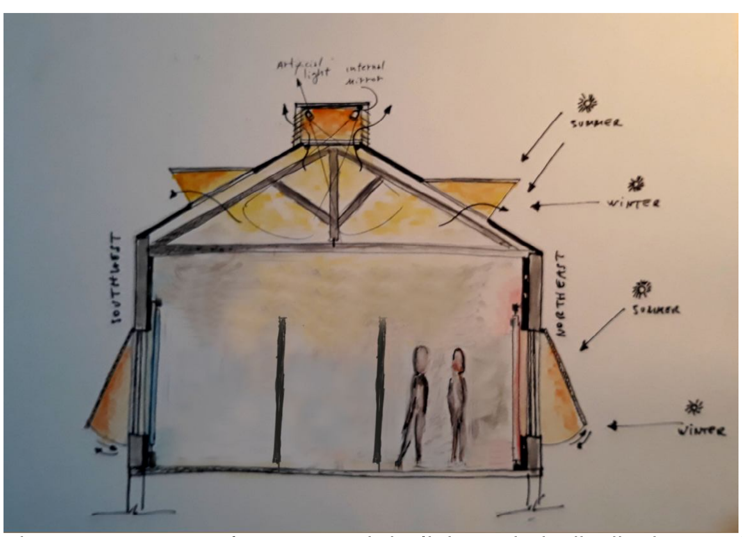


Fig. 110 - Watercolor proposed daylight and air distribution section and main sunrays direction in summer/winter.
Source: By the author

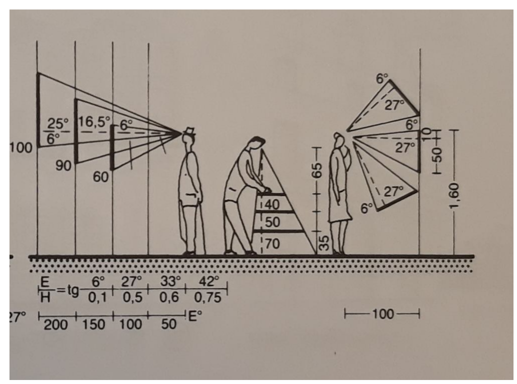


Fig. 110a - Visual field, high and separation for museums

Source: Neufert, *Arte de Projetar em Arquitetura*. Publisher:GG. 18° edition - 2013 (pg 611)

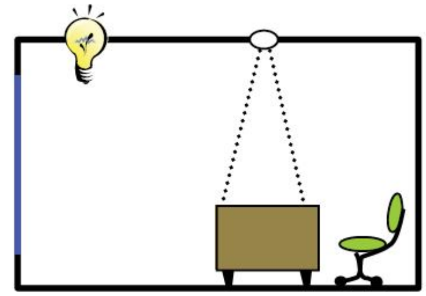
Besides the lighting control elements, others aspects were considered to achieve the intervention objectives:

f. Layout change. The actual layout of Can Framis Museum divide the floors plan into a series of small squared galleries with a lateral corridor. According to the architect of the last restoration, the concept was about industrial deposits as the main intention of the museum's direction was not a complete opened to general public. actually nowadays the museum functions in the opposite direction with visitors in all galleries. So it was proposed a layout change, more fluid, putting out the idea of a corridor and allowing daylight from both side window facades reach the paintings. The original panel divisions perpendicular to the longitudinal walls were changed to the parallel position.

g. Floor change. as the existing polished concrete floor revealed some reflection in the measurements of illuminance, the proposal is to adapt a light mate eco-friendly wood floor over the existing one.

h. Integrated daylight x artificial light system. An automated system is proposed to read the sunlight level outside on the roof and northeast, southwest facades. when the luminosity outside is intense, the sensors activate the system closing the sh**e**d louvers that receive direct daylight and closing the exterior facade blinders parcially. When the weather is cloudy the system works in opposite operation opening the exterior blinders and shed louvers and filtering daylight with internal textil screen. Frequently the sensors over the paintings (see closed loop in figure 108) inform to the system the lux level. When the lux level goes higher or down the range between 50 -150 lux, the sensors activate the system to let more available daylight get inside or to increase the artificial lights potency . The priority is to control the level of diffused daylight acquisition because the costs of energy are cheaper.

i. Artificial light fixture change or focus adjustment. The existing light fixture project light out of the paintings, illuminating also the areas of the wall, which is not desirable. The solution can be adjust the focus of the light fixture or change for a new one.



A sample private office closed loop sensor setup.*

Fig. 111

Closed loop

Closed loop is an approach to daylighting that attempts to keep the illumination at the sensor constant. This approach is task oriented; the sensor looks directly into the space of the light that it controls.

- Sensors placed inside the space, typically directly above work surface – dependent on sensor instructions
- Measures light level in a narrow viewing angle
- Adjusts electric light level up or down to maintain a desired light level on the work surface
- Affected by both electric light and daylight
- For accurate performance the sensor can only control fixtures that are contributing to the field of view
  - Generally one sensor per task surface
  - Customer would have to buy far more sensors to cover the same area
- The sensor cannot distinguish between daylight fluctuations and changes of surface reflectance

source:
https://www.google.com/search?biw=1242&bih=553&tbm=isch&sa=1&ei=1NE8XerBLJ-v5OUPzNa7wAg&q=closed+loop+sensor+method&oq=closed+loop+sensor+method&gs_l=img.3...3377.14186..14526...1.0..0.323.4025.0j25j0j1......0....1..gws-wiz-img.......35i39j0j0i67j0i10j0i30j0i19j0i8i30i19j0i8i30.VLTGyWtqX-4&ved=0ahUKEwjq-5DGlNbjAhWfF7kGHUzrDogQ4dUDCAY&uact=5#imgrc=909QBnAI6Wg_KM:
[accessed 15/07/2019]

7.3.1 FLOOR PLAN AND ROOF

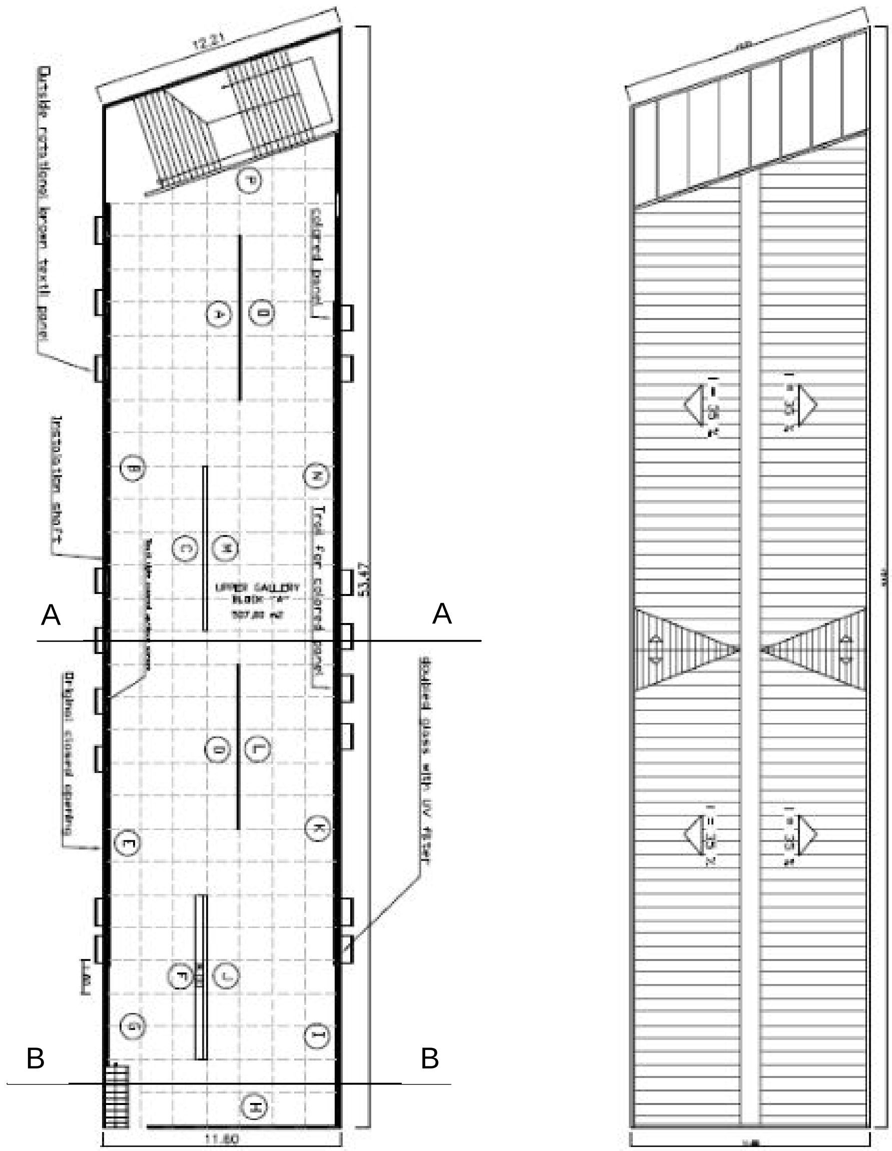
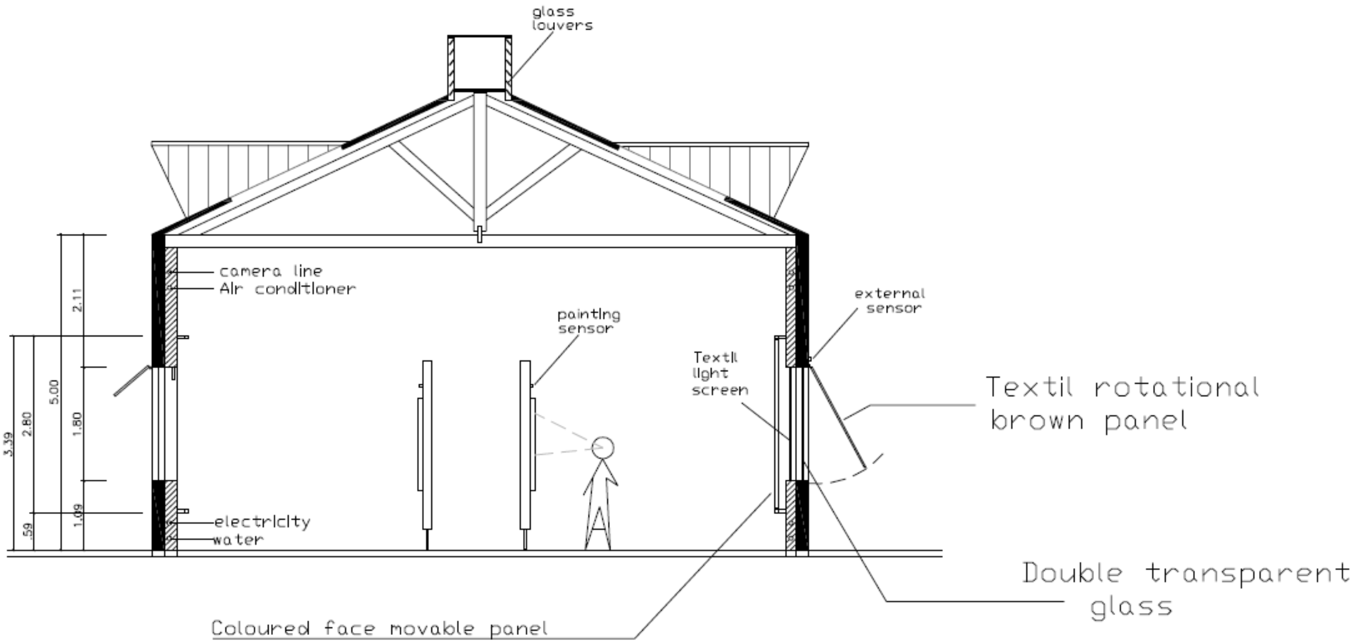


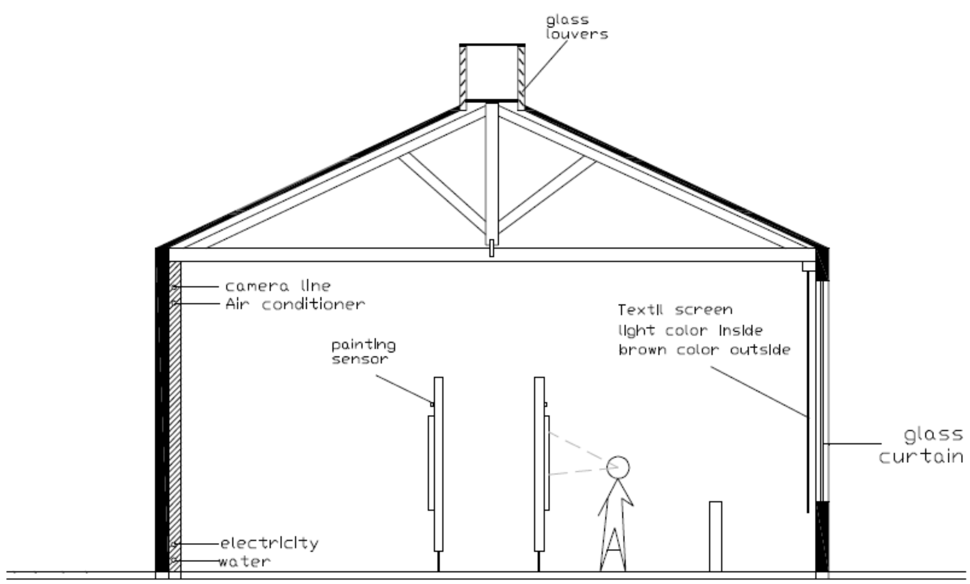
Fig. 112 - On the left side is the new proposal gallery floor plan. The circles represent the exhibition space on the lateral walls and central panels. The grid (hidden lines) was made as reference to layout base. The grid square is 1,60 x 1,60 meters. The right side shows the longitudinal shed and central triangular clerestoires.

Source: By the author

7.3.2 SECTIONS



SECTION A



SECTION B

Fig. 113 - Sections
Source: By the author

7.3.3 3D VIEWS

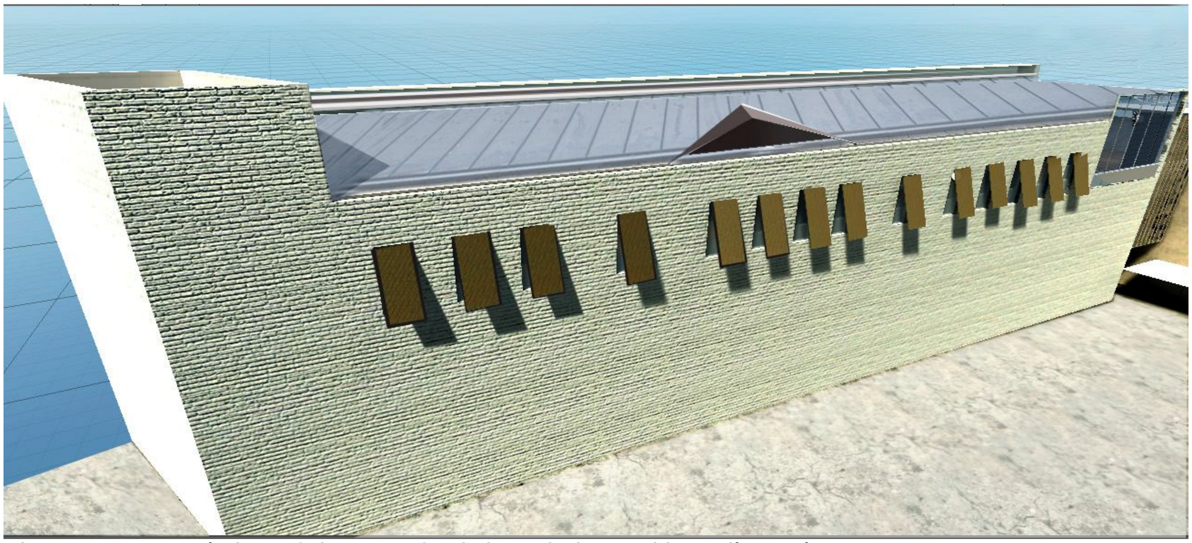


Fig. 114 - External view of the row of existing windows with textil panel and central roof clerestoire
Source: By the author

Fig. 115 - Interior view of the gallery. New wood floor avoid reflections. Longitudinal layout provides more fluidity to visitors. Lateral window daylight filtered by up/down textil screens.
Source: By the author

Fig 116 - Interior view of the gallery.
Source: By the author

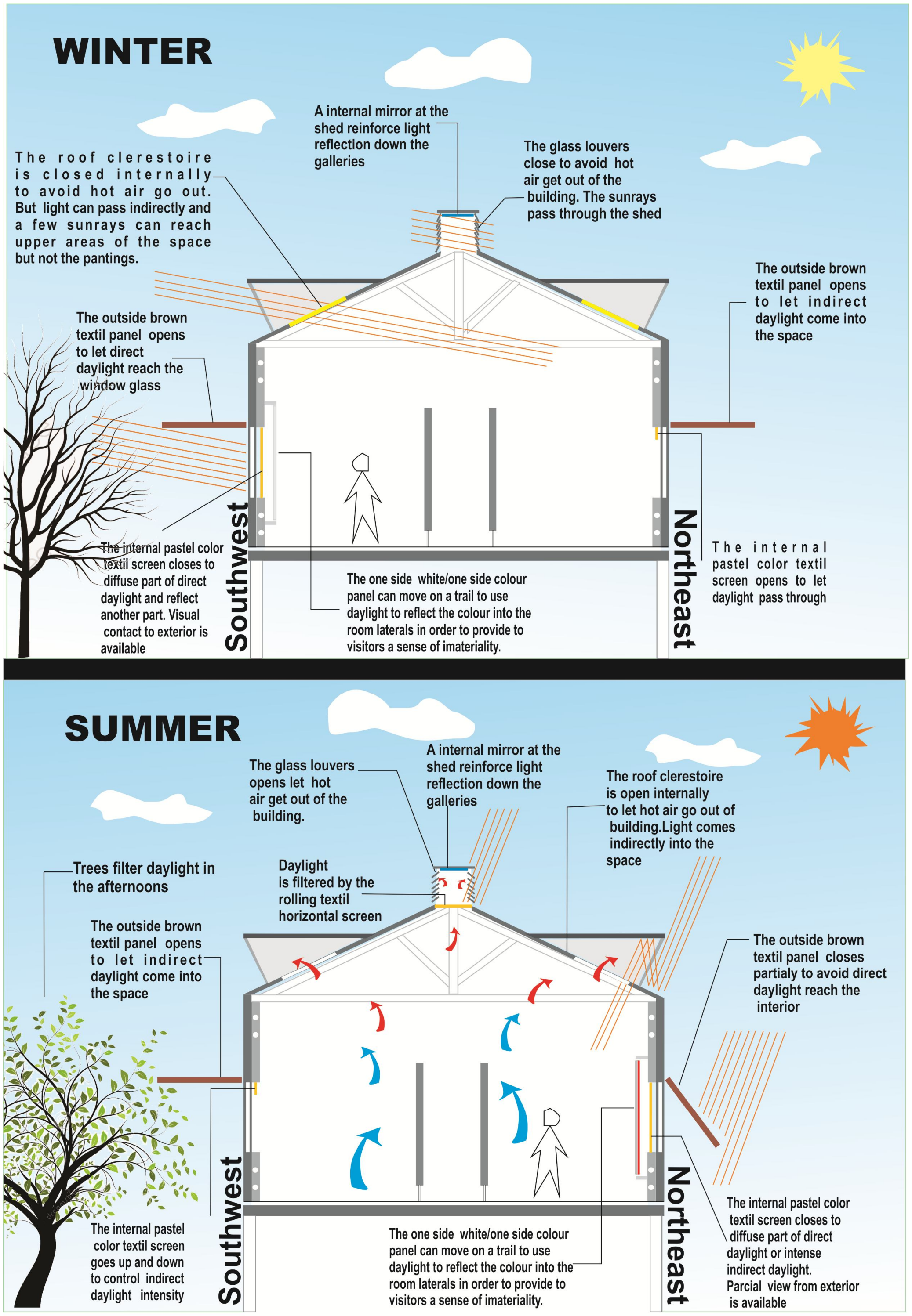


Fig. 117 - Sustainable chart. Shows the upper floor gallery function in summer and winter.

Source: By the author

8. DAYLIGHTING SCALED MODELS
X
COMPUTER SIMULATIONS

8. NATURAL LIGHTING REGISTERS X DIGITAL LIGHTING MODELING

Natural lighting is one of the individual strategies with more potential to reduce energy costs in the buildings. For this task is necessary to characterize the luminous environment precisely and quantitatively. For decades the scaled physical models has been used for natural lighting evaluation. Even though it's benefits, this method is a target for many critics basic at two points: measurements at open sky and scale effect.

Fig. 118 - Scaled model from Tadao Ando Studio. Church of Light. 1987

Source: https://archimodels.info/post/111840873107/tadao-ando-church-of-the-light-ibaraki [accessed 05/08/2019]

Great architects like Le Corbusier, Louis Kahn and Frank Lloyd Wright constructed models to develop their projects and final presentations. The model practice is not limited to the project image representation. They can be tools for the simulation of physical phenomena qualitatively and quantitatively like ventilation, structure, geometry and mainly lighting phenomena.[24]

Scientific literature affirms that natural illumination does not require compensations for scale factor in contrast with heat transmission or air fluidity. A physical scale model reduced under the same conditions that replicates the real space presents the same internal illumination pattern due to the visible light wavelength.

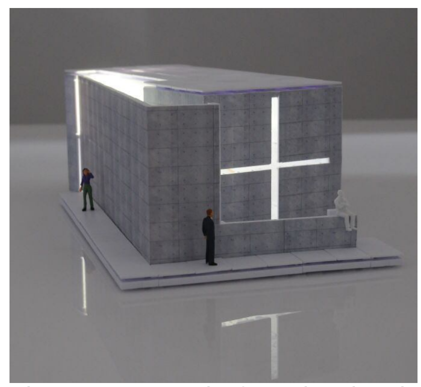


Fig. 119 - 3D model from the church of Light. Tadao Ando.
source: Google images

The main advantages of studies in scaled reduced models are (Pereira, 2011):

a) Provides precise quantitative data
b) Appropriate to complex geometry
c) allow comparisons by components change
d) Provide qualitative evaluations by observations and photography
e)It is a didactic method
f) It's familiar for architects and designers

One of the most important reason for the use of natural models are the possibility to analyze factors beyond natural lighting. Quantitative data can evaluate the efficiency of daylight, visual requirements and the necessity of artificial light. Qualitative data can help in visual comfort and perception of the space characteristics.

---

[24] Fernando Pereira, Roberto Pereira and Alexander Castano." How reliable are small physical scaled models in the evaluation of daylight in buildings" Revista Ambiente Construído, November 24, 2011.

One advantage of the physical register over the computer modeling is evident when real situations are considered in the project: a lot of spaces are not designed by simple rectangular forms or materials with knowing photometric property (NASPOLINI PEREIRA, 2004). For the success of the experiences it is important to take care about the model confection and measurements specially the optical properties of the surfaces, conditions of the environment and photometric procedures.

Fig. 120 - Le corbusier's model for the Palace of the Soviets, 1928

source: https://thecharnelhouse.org/2013/06/19/le-corbusiers-project-for-the-palace-of-the-soviets-1928-1931/ [accessed in 06/08/2019]

Disadvantages of this method are the requirements for precise quantitative data like appropriate photometric tools, which are expensive, and the extended time for the process of experiments and evaluations. Another point is the real light variation in the sky that can affect considerably the data collection in the model interior. The variation of luminances in the celest vault can reach 15% even in apparent identical days (MOORE, 1991).

For observations and evaluation of qualitative aspects of the illumination, tests under open sky are recommended because of the illuminance distribution, color reproduction and light quality generated by the Celeste vault.

9.CONCLUSION

9. CONCLUSION

The main point of this research is analyze the aspects and characteristics of natural lighting and it's changes when passing through an element that modify the light trajectory and properties. Then observe and register this aspects quantitatively and qualitatively using a scaled model unity comparing the method with the possibilities of computer simulations in order to demonstrate that natural lighting studies made into a scaled model unity is more realistic and precise. Besides this approach can answer questions beyond physical aspects and providing a real contact and understanding about daylight.

Before computer simulations became widely available, architects used physical/scale models to establish basic architectural forms for daylight analysis. With the advent of technology , more and more variables were added to interpret and offer realistic render. We can not deny the advantages of computer simulation as the use of a common methodology, independently of the type of system considered; lower marginal cost of model construction and simulation; ability to shorten or lengthen the time course of dynamic behavior (Bossel, 2007). But the results are not 100% reliable and consistent. There is a difficulty to integrate qualitative data into a computer system. Because the computer model is not the original system, there is always uncertainty about whether it describes the system behavior correctly in all its aspects.

It was found that no single software tool could meet all the needs of a designer, hence, simulation tool(s) should be selected according to the requirements of project goals and stage of design. Some programs does poorly in its offerings of advanced performance metrics and are relatively inaccurate.

The experiment of this study explicited some difficulties to get accurate conclusions about daylight control like isolation of the unit box to avoid unwanted light inside; the interference of the surrounding environment like vegetation and buildings, the variations of the sunlight to similar conditions and all the parameters that involve the measure of illuminance to identify a pattern in light performance. But the experiment was a powerful and useful tool to understand daylight quality and it's control elements in order to get to a required level for artwork, integrate visual comfort and sustainability

Fig. 121. The model unity from the experiment was used to test the side openings, skylight and blinds proposed to Can Framis Museum. Daylight only.

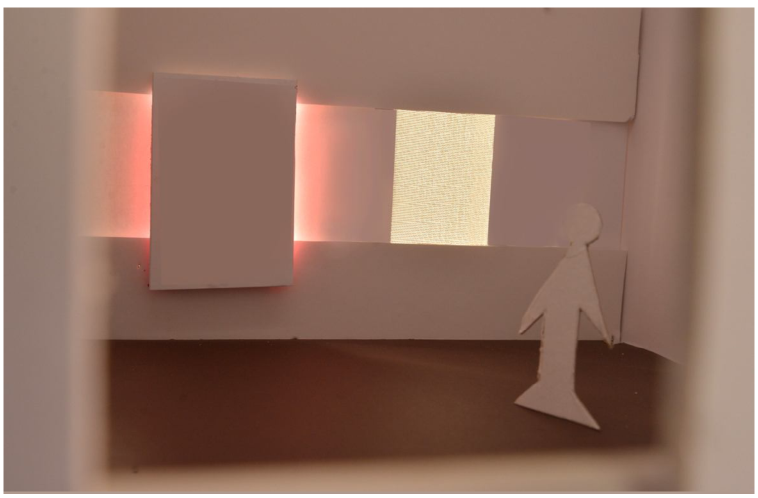


Fig. 122. Detail of the colored panel with daylight reflection. Close there is a opening with a pearl-white textil screen to diffuse light.

Model is different from simulation in that the model represents the system itself, whereas the simulation represents the operation (behavior) of the system over time" (Kosky and others, 2015; Steffy, 2008).

The Technical Building Code (CTE), the current normative since 2014 in Europe, introduced a new section about energy consume limitation pointing out that solar control is part of the definition of minimum quality of a building. A solar control index is incorporated in the facades. The energy efficiency "A" label defines that maximum 60% of the facade can be opaque and 40% can be open.

There is a demand worldwide for the use of passive cooling and solar automated control as a medium to reduce or eliminate mechanical cooling of the spaces. Lighting systems represents 14 % of the energy consume in the European Union and 19 % in the world. It is very important to consider daylight into design solutions to contribute to a sustainable world, to be more conscious about energy saving, to provide the health of the buildings and human well-been.

It is possible to daylight art exhibition spaces like museums and galleries, taking advantage of our natural light source with planning and control. Lighting management systems can activate/deactivate or dim artificial lighting in adaptation to changes in daylight. After the 50s the new museums were build with no windows because of the damage caused by daylight. But today our knowledge and technology to modern control and regulation made it possible to be precisely directed and dosed making no harm to artwork. In exhibition rooms the level of illuminance should be determined first, by the exhibit sensitivity. The second criterion is design intention and the third is the light needed for the visual task.

To reinforce the hypothesis that studies and visualizations from natural lighting in scaled models are more precise and realistic than computers simulations, a questionaire were send to some architects and designers whereas they could give their opinion about this topic.

Figures 121 and 122 show how daylight can be studied in a scaled model in order to have more realistic data to analyze natural light. The properties, distribution and luminosity is perfectly seen in the image and is identical to a space with the same dimensions and conditions.

According to Hector Zapata, architect and professor of Virtual Reality Visualization at Universitat Politècnica de Catalunya: ''The most difficult part is to create a model that is as close as possible to the final building. Not only in its geometrical shape, but specially in the materials used. I believe mimicking the materials that will be used in reality is essential to get a faithful and reliable result.''

The materials representation in the 3D images can be very realistic with the improvement of the modeling programs, but daylight characteristics and luminosity is not so reliable.

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LIST OF TABLES

APPENDICES

QUESTIONAIRE 01

AUTHOR: Yuri Guimaraes

THESES: NATURAL LIGHTING DESIGN FOR ART EXIBITION SPACES
The hypothesis is based on the demonstration that studies and registers realized into a scaled model is more realistic and reliable than computer simulations. In order to defend or question this hypothesis I would like to have your opinion and collaboration about this subject which will be mentioned in the thesis document, answering the questions below :

NAME: Héctor Zapata
PROFESSION: Architect and professor of Virtual Reality Visualization
CITY/STATE: Barcelona
DATE: August 5th 2019

1) **Before natural lighting studies were done basically in scaled models. With the advent of technology it was substituted by software simulations. In your personal projects, which methodology is used and why?**

   I always use software simulations, because it's a lot faster both preparing the initial simulation and making changes and tweaks to get the desired result.

2) **What do you think about the importance of daylight studies in physical models at the present and the advantages related to computer simulations?**

   A computer simulation is always limited to the calculation time, and thus is never perfectly accurate. A physical model can get a result that it's a lot closer to the final building.

3) **What are the difficulties in realize studies about daylight in physical models to reach reliable results?**

   The most difficult part is to create a model that is as close as possible to the final building. Not only in its geometrical shape, but specially in the materials used. I believe mimicking the materials that will be used in reality is essential to get a faithful and reliable result.

4) **In your point of view what approach is more efficient and reliable to plan sustainable solutions for architecture and why?**

   In my opinion we are currently in the middle of a threshold, or transition phase. Computer simulations are getting better every day, and although a physical model can achieve more realistic results under the right circumstances, a simulation is easier to set up and modify. So, today, it depends on the project and the level of fidelity required

   .

QUESTIONAIRE 02

Author: Yuri Guimaraes

Thesis: NATURAL LIGHTING DESIGN FOR ART EXIBITION SPACES
The hypothesis is based on the demonstration that studies and registers realized into a scaled model is more realistic and reliable than computer simulations. In order to defend or question this hypothesis I would like to have your opinion and collaboration about this subject which will be mentioned in the thesis document, answering the questions below :

NAME: Alberto Freire Olivieri
PROFESSION: Phd professor in Salvador, Brazil, Pos-Doctorate Universite de Paris VIII
CITY/STATE: Salvador, Brazil
DATE: August 14th 2019

1) **Before natural lighting studies were done basically in scaled models. With the advent of technology it was substituted by software simulations. In your personal projects, which methodology is used and why?**

   A Abordagem teórico metodológica está na questão que o ser vivo foi programado para viver com variações sensoriais. A opinião de Niemyer de que escritórios devem ter iluminação artificial e sem variação por cansar menos as vistas pode até ter um efeito metabólico mas do ponto de vista comportamental é falso, pois já fiz projetos de lay out e que em entrevistas as pessoas pediam para abrir vidros entre uma sala confinada e outra pois, trabalhar sem a luz do dia existe uma fatiga dada ao confinamento.

2) **What do you think about the importance of daylight studies in physical models at the present and the advantages related to computer simulations?**

   Não podemos esquecer que dada a transformação do objeto pela luz , os simuladores poderão destacar as obras de arte até mesmo permitir a interação do publico que possa interferir na obra través da luz permitindo uma outra leitura, permitindo uma imagem movimento simulada.

3) **What are the difficulties in realize studies about daylight in physical models to reach reliable results?**

   A questão de viabilidade financeira dos museus e salas de exposições é uma premissa importante. No entanto acredito que paralelamente à iluminação natural deverá existir um complemento de iluminação elétrica gerada pelo sol , pois em países frios existe uma variação grande de iluminamento natural, sendo importante uma vertente geográfica mostrando as potencialidades em relação aos trópicos , zona equatorial etc..
   . Assim a luz é capaz de transformar a percepção do observador, nesse sentido é importante que essa quantificação seja conhecida. Dai a importância da pesquisa pois muito se estudou a iluminação de edifícios mas não a iluminação de objetos

4) **In your point of view what approach is more efficient and reliable to plan sustainable solutions for architecture and why?**

   Os museus que possuem a utilização da luz natural em seu interior temos o Museu de Arte Contemporânea de Barcelona bem como o museu da fundação Miró nessa mesma cidade.

   No museu d'Orsay em Paris existem umas praças muito agradáveis no interior onde colocaram as esculturas originais que estavam na rua para se obter o mesmo efeito de iluminamento das ruas de Paris.